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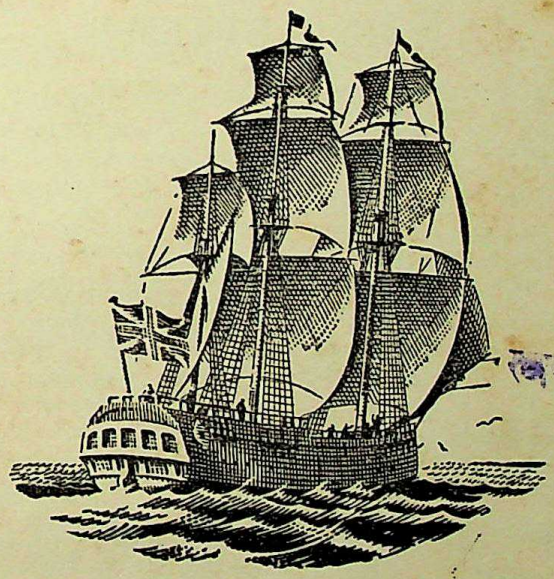

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Termination of the International Geophysical Year

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31st December 1958 marked the end of the period of concerted physical observation of the Earth and the Sun known as the International Geophysical Year. Four years of active planning were necessary before it started, and its observational phase has just been completed. This will be followed by several more years during which the observations will be collated, exchanged, published, analysed, interpreted, and discussed. The three phases of planning, observation, and data treatment have not, however, been separated so clearly as the above might suggest. Parts of the observational phase began before 1st July 1957, and some will continue after 31st December 1958: likewise the collection and discussion of the data began soon after the Year opened.

Over sixty nations have taken part in the project. Its growth to become by far the greatest international enterprise of co-operative scientific research ever undertaken astonished its initiators. Of the latter, the principal was Lloyd V. Berkner, who in 1950 proposed that in 1957–58 there should be a third International Polar Year, to succeed the first and second polar years of 1882–83 and 1932–33.

The organization has been marked by simplicity of method. There has been little protocol, and the central administration has been surprisingly small in staff and in cost, considering the magnitude of the enterprise. The national scientific academies have been its mainstay. It was they who appointed the committees that organized the national programmes in conformity with plans internationally devised. It was they who persuaded their own governments of the importance and value of these plans, and thereby gained the necessary authority and funds for their national participation. The academies aroused the interest and secured the valuable aid of the press, so that people throughout the world came to know of the International Geophysical Year.

As early as 1950 it was expected that 1957–58 would nearly coincide with a sunspot-maximum period. The solar activity during this period has, in fact, proved to be of an intensity unprecedented during the two centuries or more of reliable quantitative estimation. Consequently there have been many specially interesting solar flares, auroras, and magnetic and ionospheric storms affecting also cosmic rays. The detailed scientific results are far too numerous even to outline here.

Two particularly interesting features of the International Geophysical Year achievements are observations carried out in the Antarctic and the launching of earth satellites. Our knowledge of the great southern continent has leaped forward: its study will continue without a break, although in 1959 on a somewhat reduced scale. At the beginning of the International Geophysical Year the satellite part of the programme was a hope, indeed an expectation, but one not unmingled with doubt. The launching of the first Russian satellite on 4th October 1957 marked a new epoch in the history of our race. By the time of the last full meeting of the central organizing body in Moscow last August seven satellites had been launched, three by Russia and four by the United States. Already they have revealed important new results, though many of their data still remain to be studied and published. They have shown that the Earth's atmosphere extends further into space than had been thought, and that above a few hundred miles there is a layer, hitherto unsuspected, in which there are electrons of considerable energy, although much less than that of cosmic rays.

In a world suffering from serious political tensions the International Geophysical Year has been a unifying force. Participation has been open to the academies of all countries, without regard to the colour, race, religion, or mode of government of their people. Among the few notable—and much-regretted—gaps in participation only one has been due to political considerations.

The International Geophysical Year has also been a unifying force in the geophysical and solar sciences. Their international aspects have long been under the care of several international scientific unions—of geodesy and geophysics, of astronomy, of scientific radio, of pure and applied physics, of geography, and so on. The common interests of the unions have been watched over by the International Council of Scientific Unions (ICSU), composed of representatives of the unions and of the national scientific academies. The central organizing body of the International Geophysical Year (CSAGI) represents the International Council and the unions, and not the nations to which they belong. The central

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organizing body has been assisted by an advisory council composed of one representative of each adhering nation or territory. There has in the past been much inter-union co-operation between scientists working in the different branches of geophysics and solar physics, but never before has this been so effective, intimate, and widespread as in the International Geophysical Year.

In executing their agreed shares in the enterprise the nations concerned have co-operated generously and freely. There has been no bargaining about their respective contributions: each nation has done what it could, at its own cost, and there have been many instances of mutual help. The same liberal principles govern the use of the observations made. The data obtained are to be available to scientists everywhere, regardless of whether their countries contributed much, little, or nothing at all.

The expenses of the central organization—for secretariat, meetings, publications, and so on—have been met from several sources. Initially the International Council of Scientific Unions was the sole provider. Then the United Nations Educational, Scientific and Cultural Organization became a generous supporter, both financially and in other ways. Later the participating committees gave generously to the CSAGI funds, on a free-will basis. Together with such gifts must be mentioned the devoted personal services of tens of thousands of scientists—and secretarial and other assistants—sometimes under hard conditions of tropical heat or polar cold or ocean storm. The International Geophysical Year has been served with enthusiastic loyalty and beyond common measure by men and women in all parts of the world. Among their motives have been a desire for knowledge and a sense of unity with all races of mankind in a peaceful enterprise for the benefit of all.

Such idealism, and a spirit of friendly emulation, have marked the approach to a multitude of International Geophysical Year problems. Those concerned have reviewed anew the complicated physical phenomena of our planet and the Sun. To help to study them they have devised many new instruments and kinds of apparatus for observation. They have planned the use of these devices on land and sea and in the air; this frequently involved complex tasks of organization. New institutions have been set up, such as centres for forecasting terrestrial disturbances energized by storms on the Sun, and World Data Centres in which the observations will be stored and from which they will be made universally available. One such centre is at Slough, England, for rocket and satellite data. To assist the organization of these data centres a special full-time officer, the Co-ordinator, was appointed in 1956; his branch of the central organization will close late this year, but the centres themselves will be continuing institutions. The solar terrestrial forecasting centre and the complex communications system associated with it have been the charge of one of the fourteen CSAGI Reporters, each of whom was responsible for one section of the plan.

Twelve of the Reporters have undertaken chief responsibility for planning the twelve different main sections of the programme—meteorology, geomagnetism, aurora and airglow, ionosphere, solar activity, cosmic rays, latitudes and longitudes, oceanography, glaciology, seismology, gravimetry, and nuclear radiation. One Reporter has acted similarly in regard to the rocket and satellite programme, which has concerned several of the twelve sections. The work of these Reporters will continue during the third phase of the project.

In August 1957 the CSAGI held a final meeting in Moscow to approve the plans for the third phase. Many of the observations already made were discussed and the plans for the collection, publication, and interpretation of the data were considered. At this meeting the Russian committee proposed an extension of the International Geophysical Year enterprise until the end of 1959. They pointed out that the expense of setting up many new stations for various kinds of observation had already been incurred, and that to maintain them for another year would materially add to the data at a relatively small cost, especially in the case of stations that had started late. The Russian committee won agreement in urging that ICSU should organize the continuation of the valuable new features of the International Geophysical Year organization after the main project is over. The CSAGI also approved the continuation of the International Geophysical Year programme, so far as is possible for the national committees, under the new name of International Geophysical Corporation 1959. Thus although the International Geophysical Year period of observation has ended, much of the programme and institutions will continue, at least for the present year, and the present and succeeding years will see the gradual threshing of the great harvest of knowledge so far gathered.

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The transuranium elements

GLENN T. SEABORG

No transuranium elements were known twenty years ago, but today there are ten, all essentially synthetic elements, one of which has been prepared on a relatively large scale, and news of others seems imminent. The preparation and identification of these elements involves new bombardment techniques and new methods of analysis adapted to small quantities of short-lived elements. These techniques, and the results achieved by them, are discussed here by one who has for many years been most intimately concerned with this research.

The study of the transuranium elements is an exciting branch of science, which started less than twenty years ago and has a clearly discernible future of great expansion. These elements represent the realization of the alchemists' dream of transmutation. They have played an important role in the recent renaissance of inorganic chemistry. An advance as fundamental as a ten per cent increase in the number of chemical elements has, as one might anticipate, contributed much to our fund of the most basic scientific knowledge, especially in the fields of chemistry and physics.

The chemistry and physics of the longer-known transuranium elements are already remarkably developed, and extremely interesting. Neptunium has an isotope sufficiently long lived to be safe to handle with moderate precautions in ordinary laboratories; plutonium and curium have similarly long-lived isotopes which should eventually make these elements available for broader investigation throughout the world when they become more available. One of the transuranium elements, plutonium, is particularly interesting. It has an isotope with nuclear properties such that it is destined to play an extremely important role in the history of mankind. Plutonium was discovered and methods for its manufacture were worked out under the cloak of secrecy during the last war. It was the first synthetic element to be seen by man and the first example of large-scale production of an element by transmutation. Plutonium has most unusual chemical and metallurgical properties. For example, it has four oxidation states which may exist in aqueous solution in equilibrium with each other at appreciable concentrations. The metallic form has six allotropic modifications between room temperature and its melting point, some with properties unknown in any other metal. The alpha-radioactivity and physiological behaviour of its fissionable isotope, Pu^{239}, make this one of the most dangerous known poisons. The announcement of its discovery to the world was through the atomic bomb that fell on Nagasaki. Plutonium, of course, has an important future in nuclear power. The fissionable isotope Pu^{239} makes its source isotope U^{238}, which is not fissionable with slow neutrons, a potential nuclear fuel. The fertile U^{238} is 'burned' by going through the intermediate fissionable Pu^{239}.

The discovery of the first transuranium element followed a false start six years earlier. When Enrico Fermi and his co-workers first bombarded uranium with slow neutrons in 1934 they found that a number of artificially radioactive species were produced, and in the immediately following years many more such substances were observed. Most of these were thought to be transuranium elements. Chemical investigation, however, led to the discovery of the fission process rather than to the discovery of transuranium elements. Subsequent work has shown that practically all the radioactive species believed to be transuranium elements were in fact fission products of uranium. In 1940 E. M. McMillan and P. H. Abelson discovered the first transuranium element. This was neptunium, with atomic number 93. In the following years, many more transuranium elements, plutonium (94), americium (95), curium (96), berkelium (97), californium (98), einsteinium (99), fermium (100), mendelevium (101), and element 102 were synthesized and identified. The elements up to and including einsteinium have isotopes sufficiently long lived to be isolated in macroscopic, that is weighable, quantities, but this does not seem to be true beyond einsteinium.

The transuranium elements are, for all practical purposes, synthetic in origin and must be produced by transmutation, starting, in the first instance, with uranium. However, two of them, neptunium and plutonium, are present in trace concentrations in uranium ores as the result of the action of the neutrons which are present. Investigation

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of these new elements has resulted in the contribution of much information to inorganic chemistry, since they have a rich and varied chemical behaviour, form unusual compounds, and in some cases display an extraordinary complexity in solution. The relationship of these elements to each other and to the other elements is now within our understanding. Problems inherent in the study of these elements, such as those of handling quantities of material so small as to be unweighable, of working in safety with radioactive materials, and of preparing and identifying elements of ever increasing atomic number, are being solved.

POSITION IN THE PERIODIC TABLE

Ideas on the position in the Periodic Table (Table 1) of the heaviest elements have varied considerably over the years. Until the last war, thorium, protoactinium, and uranium were commonly placed immediately below the elements hafnium, tantalum, and tungsten, which are members of a transition series in which the 5d electron shell is being filled. This placing was based on the assumption that the three heavy elements were members of a 6d electron transition series. The appearance of N. Bohr's paper on the quantized nuclear atom in 1913 led to suggestions that a 5f electron transition series should start in the region thorium to element 95 inclusive, before the completion of the 6d electron shell. With the discovery of neptunium and then plutonium, the boundaries of the Periodic Table were transcended, and as knowledge of the first transuranium elements accumulated, it became evident that a whole new family of elements, some known and some still to be discovered, existed in this region of the Periodic Table.

The fact that the transuranium elements are members of a transition series similar to the rare earth, or lanthanide, series is useful in predicting the chemical properties of these elements before they are actually detected. This particular pattern of similarity, recognized by the author in 1944 on the basis of the chemical properties of neptunium and plutonium, was the key to the discovery of elements 95 and 96 (americium and curium) and has been essential to the discovery of the transcurium elements. Since all the elements beyond actinium seem to belong to the actinide group (a name chosen by analogy with the lanthanide group), the elements thorium, protoactinium, and uranium have been removed from the positions they occupied in the Periodic Table before 1939 and placed in this transition family; as we shall see, elements 104, 105, and 106 will presumably take over the positions previously held by thorium, protoactinium, and uranium. Thus we have the interesting result that the newcomers have affected the face of the Periodic Table, and a change has been made after many

TABLE I

1 H 1·0080																	2 He 4·003
3 Li 6·940	4 Be 9·013											5 B 10·82	6 C 12·011	7 N 14·008	8 O 16·000	9 F 19·00	10 Ne 20·183
11 Na 22·991	12 Mg 24·32											13 Al 26·98	14 Si 28·09	15 P 30·975	16 S 32·066	17 Cl 35·457	18 A 39·944
19 K 39·100	20 Ca 40·08	21 Sc 44·96	22 Ti 47·90	23 V 50·95	24 Cr 52·01	25 Mn 54·94	26 Fe 55·85	27 Co 58·94	28 Ni 58·71	29 Cu 63·54	30 Zn 65·38	31 Ga 69·72	32 Ge 72·60	33 As 74·91	34 Se 78·96	35 Br 79·916	36 Kr 83·80
37 Rb 85·48	38 Sr 87·63	39 Y 88·92	40 Zr 91·22	41 Nb 92·91	42 Mo 95·95	43 Tc	44 Ru 101·1	45 Rh 102·91	46 Pd 106·4	47 Ag 107·880	48 Cd 112·41	49 In 114·82	50 Sn 118·70	51 Sb 121·76	52 Te 127·61	53 I 126·91	54 Xe 131·30
55 Cs 132·91	56 Ba 137·36	57 La See La series	72 Hf 178·50	73 Ta 180·95	74 W 183·86	75 Re 186·22	76 Os 190·2	77 Ir 192·2	78 Pt 195·09	79 Au 197·0	80 Hg 200·61	81 Tl 204·39	82 Pb 207·21	83 Bi 208·99	84 Po	85 At	86 Rn
87 Fr	88 Ra 226·03	89 Ac See Ac series	(104)	(105)	(106)	(107)	(108)										

Lanthanide series	57 La 138·92	58 Ce 140·13	59 Pr 140·92	60 Nd 144·27	61 Pm	62 Sm 150·35	63 Eu 152·0	64 Gd 157·26	65 Tb 158·93	66 Dy 162·51	67 Ho 164·94	68 Er 167·27	69 Tm 168·94	70 Yb 173·04	71 Lu 174·99
Actinide series	89 Ac 227·04	90 Th 232·05	91 Pa 231·05	92 U 238·04	93 Np 237·06	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 E	100 Fm	101 Mv	102	(103)

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years during which it seemed to have assumed its final form.

NEPTUNIUM

The discovery of the first transuranium element, neptunium, resulted from McMillan's investigation of the fission process. In measuring the energies of the two main fragments from the neutron-induced fission of uranium, he found that there was another radioactive product of the reaction, one which did not recoil sufficiently to escape from the thin layer of uranium undergoing fission. He suspected that this was a product formed by neutron capture in the uranium. McMillan and Abelson were able to show on the basis of their chemical work that this product was an isotope of element 93 (Np^{239}), arising by beta decay of U^{239} formed by neutron capture in U^{238}.

It was not obvious what the electronic configuration and chemical properties of neptunium might be. Uranium was known to have some similarity to tungsten, and it was thought that element 93 might resemble rhenium, the next element beyond tungsten. There was the possibility, however, that neptunium might be a member of some new type of transition series among the heavy elements. McMillan and Abelson's investigation of neptunium showed that it resembles uranium, not rhenium, in its chemical properties. This was the first definite evidence that the 5f electron shell is filled in the transuranium region.

The early investigation of neptunium, as of all the transuranium elements, was made by the tracer technique. In this method, an element having chemical properties similar to those of the element being studied is used to follow the behaviour of the radioactive element, which is present in amounts as small as 10^{-10} g, or even less. The element is followed in the various reactions by means of its radioactivity rather than by chemical analysis. In spite of the smallness of the quantities present, much can be deduced about the chemical properties of an element—for example, the solubility of its compounds, its oxidation-reduction potentials, and its formation of complex ions—by the use of such methods.

PLUTONIUM

Plutonium was next to be discovered. By bombarding uranium with deuterons, E. M. McMillan, J. W. Kennedy, A. C. Wahl, and the author, in late 1940, succeeded in preparing a new isotope of neptunium, Np^{238}, which decayed to Pu^{238}. The half-life of this isotope was found to be sufficiently long to permit detection and to make possible our obtaining considerable chemical information about it by tracer studies. Armed with this information about the new elements, J. W. Kennedy, E. Segrè, A. C. Wahl, and the author in 1941 identified the most important plutonium isotope, Pu^{239}, as the decay product of Np^{239} and we were able to prove that Pu^{239} undergoes fission with slow neutrons.

The realization that plutonium, as Pu^{239}, could serve as a nuclear weapon and that it might be created in quantity in a nuclear chain reactor made it imperative to carry out chemical investigations of plutonium with microgram quantities. In August 1942, B. B. Cunningham and L. B. Werner succeeded in isolating about a microgram of Pu^{239} which had been prepared by cyclotron irradiations. Thus plutonium was the first man-made element to be obtained in visible quantity.

A background of manipulative techniques for this ultramicrochemical work was provided by the pioneer investigations of P. L. Kirk and A. A. Benedetti-Pichler. If extremely small volumes are used, even microgram quantities of material can give relatively high concentrations in solution, and with the development of balances of the required sensitivity, micrograms were also sufficient for gravimetric analysis. Liquid volumes in the range 10^{-1} to 10^{-5} ml were measured with an error of less than one per cent by means of finely calibrated capillary tubing, the movement of liquid being controlled by air pressure. Smaller pipettes were constructed to fill by capillary action. Chemical glassware, such as test tubes and beakers, was constructed from capillary tubing having an internal diameter of 0·1–1 mm and was handled with micromanipulators. The weights of solid reagents and precipitates handled in ultra-microchemical work are usually in the range of 0·1–100 μg. There are some changes in method involved in the change of scale—thus, solids are usually separated from liquids by centrifuging rather than by filtration. The actual chemical work is usually done on the mechanical stage of a microscope, where the essential apparatus is within view (figure 2). Among the early accomplishments in ultramicrochemistry were the isolation of pure neptunium (figure 3) and pure plutonium compounds (figure 4) as well as the preparation of plutonium metal. Figures 1 and 5 show schematic drawings of the experimental arrangements used in the preparation of pure plutonium metal and pure plutonium trichloride.

Plutonium is the only synthetic element that has

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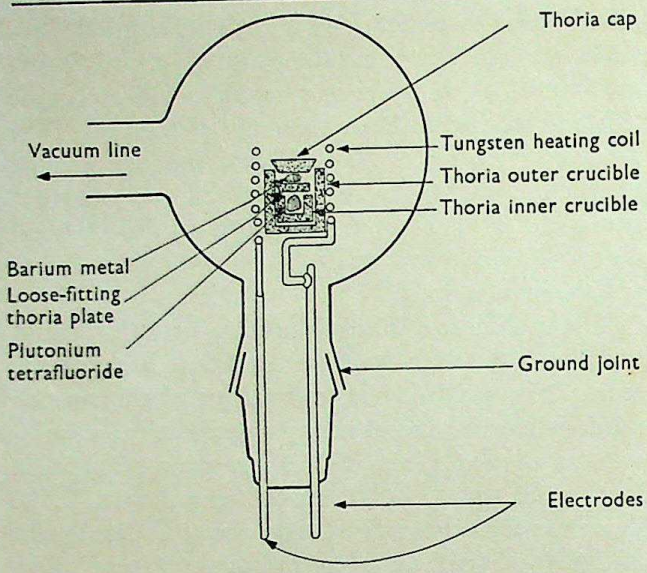

FIGURE 1 – *Apparatus used in the first preparation of plutonium metal (November 1943). 35 μg of plutonium tetrafluoride was treated with volatilized barium metal in a thoria crucible at 1400° C. The metallic plutonium was produced as silvery globules weighing about 3 μg each.*

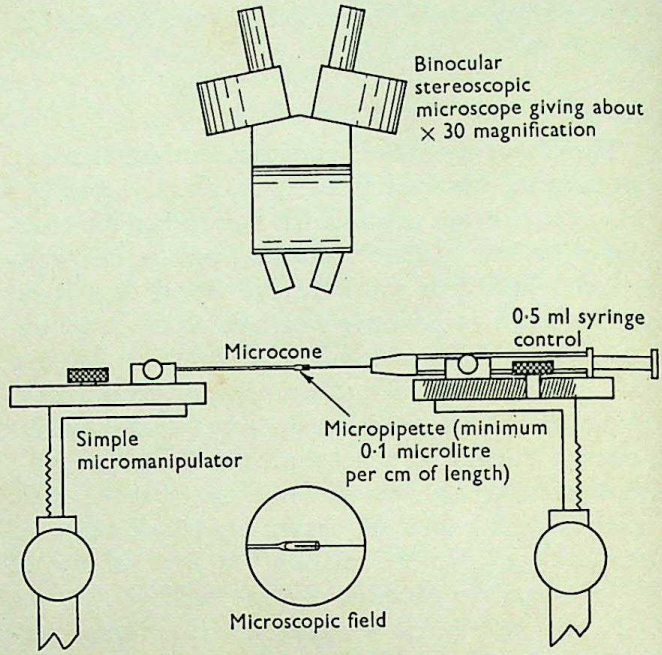

FIGURE 2 – *Experimental arrangement for the study of precipitation reactions on the microgram scale.*

been produced and isolated in kilogram quantities. The large plant at Hanford, Washington, was constructed on the basis of investigations performed with about 2 mg of plutonium; the scale-up between ultramicrochemical experiments to the final Hanford plant corresponds to a factor of about 10^9, surely a scale-up of unique proportions.

Frequently chemical investigation of plutonium and of other transuranium elements is carried out on a scale of a milligram or less by choice, rather from any limitation on supply—Pu^{239} is exceedingly toxic because of its high alpha-radioactivity, amounting to about 140 000 000 alpha-disintegrations per minute per milligram; special equipment and precautions, as well as the use of material in very small amounts, are necessary when working with it.

AMERICIUM AND CURIUM

After plutonium had been produced in quantity, the discoveries of americium (1944–5) and curium (1944) were made. The speed of discovery of these elements was due largely to the accurate prediction of their chemical properties on the basis of their assumed position in the Periodic Table (page 6). Curium, discovered by R. A. James, L. O. Morgan, A. Ghiorso, and the author, was synthesized as Cm^{242} by the bombardment of plutonium with helium ions. The production of americium by James, Ghiorso, and the author was accomplished by preparing Pu^{241}, which decays by beta emission to Am^{241}.

IDENTIFICATION BY ION EXCHANGE

The ion-exchange technique, coupled with element-by-element comparison of the behaviour of corresponding actinide and lanthanide elements, has been essential in the discovery of the transuranium elements. Since the actinide elements above plutonium are predominantly trivalent in solution and have a close chemical resemblance, most conventional chemical separations are not suitable. Again, the first isotopes of the new actinide elements were obtained in very small amounts, and are very short-lived. Specific and rapid methods are therefore necessary in identifying these elements, and ion exchange provides both. Much of the chemical knowledge we have of the actinide elements heavier than curium is concerned with their ion-exchange and elution properties.

The trivalent actinide and lanthanide ions in aqueous solution undergo a cation exchange when a solid organic base-exchange polymer is stirred in. The solid material can then be placed at the top of a glass column filled with more of the organic polymer that is free of the actinides or lanthanides. Elution can then be accomplished by pouring through the column a solution containing ions that form complex ions with the actinide or lanthanide ions. In certain well-behaved systems the lanthanide elements elute from the column in the inverse order of their atomic numbers, that is, lutetium can be collected as the first element in the drops coming through the column, ytterbium

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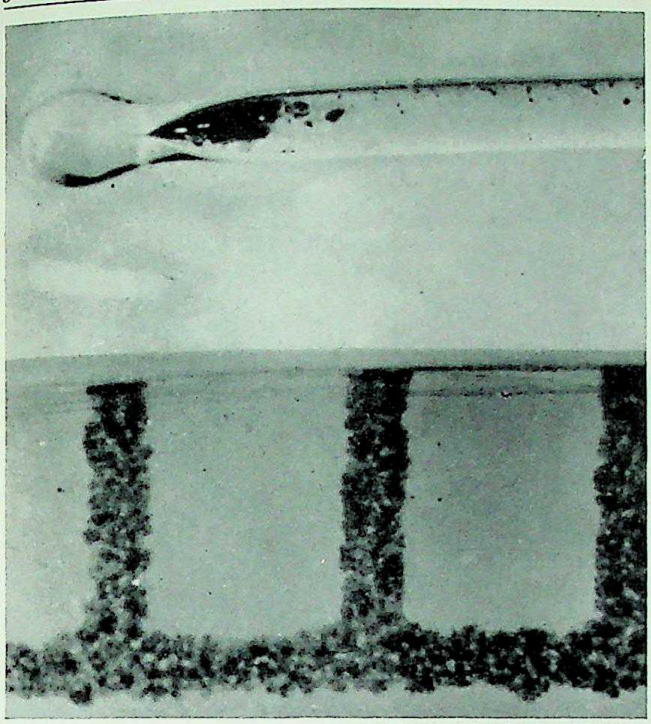

FIGURE 3 – *First neptunium compound isolated. The neptunium, present as the oxide, appears at the bottom of the capillary tube. The sample was isolated in* 1944 *and weighed about* 10 μg. *Below the sample, for purposes of comparison, is a millimetre scale.*

FIGURE 4 – *First plutonium compound to be weighed* (10*th September* 1942). *The plutonium, present as the oxide, appears as a crusty deposit, indicated by the arrow, near the end of a platinum weighing boat which is held by forceps. The weight of the plutonium oxide was* 2·77 μg. (×20)

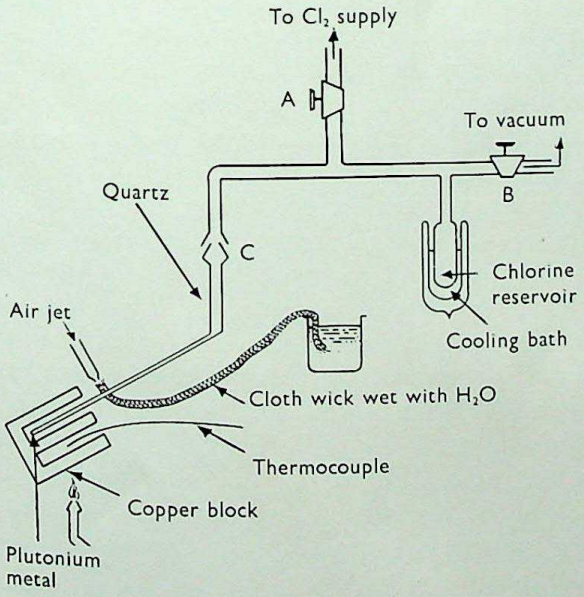

FIGURE 5 – *Apparatus used in the first preparation of* $PuCl_3$ (*February* 1944). *The compound was prepared by treating a* 50 μg *piece of plutonium metal with chlorine gas. After placing the plutonium in the capillary tube, the system was evacuated. Chlorine gas was added, and a small amount condensed in a reservoir as shown. The system was closed and remained filled with chlorine at a pressure of about* 60 *mm Hg. The copper block was heated to* 45° *C, and the reaction product was formed in the top of the capillary tube. The section of the capillary containing the product was sealed off and the compound formed was identified by X-ray diffraction.*

as the second element, and so on to cerium. The whole process bears a close resemblance to chromatography. In the case of the actinides, the undiscovered element 103 will leave the column first, followed by element 102, and so on down the scale of atomic numbers.

BERKELIUM AND CALIFORNIUM

At the end of 1949 and beginning of 1950, experiments led to the production of elements 97 and 98, berkelium and californium. The first six transuranium elements were discovered almost in pairs, with time lapses corresponding to necessary improvements in technique and the accumulation of starting material. Milligram amounts of americium for target material were prepared by the intense neutron irradiation of plutonium for a long time; this process builds up the heavier elements by a series of neutron captures. Curium for target material was prepared in microgram amounts by the neutron irradiation of some of the americium. Both of these neutron bombardments were carried out in high-flux reactors. Berkelium, as the isotope Bk^{243}, was discovered by S. G. Thompson, A. Ghiorso, and the author in December 1949, as a result of the bombardment of americium with helium ions. Californium was first synthesized and identified by S. G. Thompson, K. Street Jr, A.

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Ghiorso, and the author in February 1950, the isotope Cf^{245} being produced by the bombardment of microgram amounts of curium with helium ions. The identification of californium was accomplished with a total of about 5000 atoms.

EINSTEINIUM AND FERMIUM

The first test thermonuclear explosion, which took place in the Pacific in November 1952, led to the discovery of elements 99 and 100, einsteinium and fermium. These two elements were found in debris, collected first on filter papers attached to aeroplanes which flew through the explosion area and later in more substantial quantities by gathering up surface materials from a neighbouring atoll. The uranium in the fission-fusion device was subjected to an instantaneous intense neutron flux which gave rise to very heavy uranium isotopes. These rapidly decayed into heavy isotopes of plutonium, americium, curium, berkelium, californium, and elements 99 and 100. These reaction products were investigated by groups at the University of California Radiation Laboratory, Argonne National Laboratory, and Los Alamos Scientific Laboratory. The two elements were discovered by Ghiorso and co-workers at the three laboratories.

Einsteinium and fermium can be synthesized by a number of methods. Chief among these is the irradiation of plutonium for several years with an extremely high neutron flux in such a reactor as the Materials Testing Reactor at Arco, Idaho. The einsteinium used to produce element 101 was prepared in the Materials Testing Reactor.

MENDELEVIUM

The synthesis of element 101 was planned and accomplished not only with an amount of target einsteinium (E^{253}) so small as to be unweighable, but also with the expectation that no more than one atom of element 101 per experiment would be produced. Only about one thousand million atoms of E^{253} were available for target material. In addition, the separation of the one atom of element 101 from the 10^9 atoms of target einsteinium and its ultimate complete chemical identification by separation in the eka-thulium position by the ion-exchange method would have to be accomplished. These requirements necessitated new techniques, and also some luck; fortunately, both were forthcoming. The new technique involved the separation of element 101 from the einsteinium in the target by the recoil method. The einsteinium was plated on to a gold foil in an invisibly thin layer. The helium-ion beam was sent through the back of the foil so that the atoms of element 101, recoiling because of the momentum of the impinging helium ions, could be caught on a second thin gold foil. This second gold foil, containing recoil atoms, yet relatively free of the target einsteinium, was dissolved and the chemical separations were performed. Very sensitive methods were available for the detection of isotopes decaying by alpha-particle emission or by spontaneous fission. These methods were so efficient that as little as one or two atoms of element 101 per experiment could be detected.

The earliest experiments were confined to looking for short-lived alpha-emitting isotopes that might be due to element 101. However, no alpha activity was observed that could be attributed to element 101, even when the time between the end of the bombardment and the beginning of the alpha-particle analysis was reduced to five minutes.

The experiments were continued, and in one of the subsequent bombardments, a single large pulse due to spontaneous fission was observed. Chemical experiments indicated that the spontaneous fission counts, when they did appear, came in chemical fractions corresponding approximately to element 100 or 101. In the definitive experiments, three successive three-hour bombardments were made, and, in turn, their transmutation products were completely and quickly separated by the ion-exchange method. A total of five spontaneous fission counts was observed in the elution position corresponding to element 101, while a total of eight spontaneous fission counts was also observed in the element 100 position. No such counts were observed in any other position. The spontaneous fission activity in both the element 101 and 100 fractions decayed with a half-life of about three hours. This and other evidence led to the view that the isotope has the mass number 256 and decays by electron capture, with a half-life of the order of an hour, to the isotope Fm^{256} which is responsible for the spontaneous fission decay.

On the basis of this evidence, the group, consisting of A. Ghiorso, B. G. Harvey, G. R. Choppin, S. G. Thompson, and the author announced the discovery of element 101. We gave the new element the name mendelevium in recognition of the pioneering role of Dmitri Mendeleev, who was the first to use the periodic system of the elements to predict the chemical properties of undiscovered elements. Subsequent experiments using larger amounts of einsteinium in the target

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have led to the production of over one hundred atoms of mendelevium. The indications are that mendelevium is a typical tripositive actinide element and a true eka-thulium, as expected.

ELEMENT 102

The discovery of element 102 was announced in 1957 as the result of work done at the Nobel Institute for Physics in Stockholm by a team of scientists from the Argonne National Laboratory, the Atomic Energy Research Establishment at Harwell, and the Nobel Institute. An isotope of the element was reportedly produced by bombarding Cm^{244} with cyclotron-produced $C^{13(+4)}$ ions and decayed with a half-life of about ten minutes by the emission of 8·5 MeV alpha particles. The name nobelium for element 102 was suggested by this group. Unfortunately it has not been possible to confirm this discovery in experiments performed at the University of California Radiation Laboratory. In April 1958 a group consisting of Ghiorso, T. Sikkeland, J. R. Walton, and the author at the Radiation Laboratory identified the isotope 102^{254} as a product of the bombardment of Cm^{246} with C^{12} ions accelerated in the new heavy-ion linear accelerator there. (The reaction is $Cm^{246}(C^{12}, 4n)$ 102^{254}). The element 102 isotope decays by alpha-particle emission with a half-life of about 3 seconds. It was detected by the chemical identification of its known daughter Fm^{250}, the atoms of the daughter element being separated from the parent element 102 by taking advantage of the recoil due to element 102 alpha-decay. Although the name nobelium for element 102 will undoubtedly have to be changed, the investigators have not, at the time of writing, made their suggestion for the new name.

COMPARISON OF ACTINIDES AND LANTHANIDES

The resemblance between the actinide and lanthanide elements suggests that their electronic structures must be similar. In the lanthanide elements, the fourteen 4f electrons are added one by one, beginning with cerium (atomic number 58) and ending with lutetium (atomic number 71). In the actinide elements, fourteen 5f electrons are added, beginning formally with thorium and ending with element 103. The evidence for this, which is too complex and lengthy to discuss in this article, lies in the chemical properties, absorption and fluorescence spectra in aqueous solution and crystals, crystallographic structure data, magnetic data, and spectroscopic data. The lanthanide gadolinium, with seven 4f electrons, and the actinide curium, with seven 5f electrons, are of especial interest because of the enhanced stability of the half-filled f-electron shell configuration. The two elements have been found to have properties that are strikingly similar. The family relationship within the actinide group means that the study of any one of them often gives indirect information about the chemical properties of another. Thus certain anomalous elution sequences among the transplutonium elements have made it possible to make deductions about the chemical properties of plutonium in relation to its electronic structure.

There are important differences between the actinide and lanthanide elements, however, due largely to the lower binding energies and less effective shielding by outer electrons of 5f (as compared to 4f) electrons. It appears that the first 5f electron is not present in thorium. Evidence to date indicates that uranium possesses three 5f electrons. The additional 5f electrons apparently are added to the succeeding elements in a regular fashion, proceeding through curium with its half-filled shell to the as yet undiscovered element 103 which presumably will have fourteen 5f electrons. In the early members of the actinide group particularly, the lower binding energies of the 5f electrons compared to the 4f electrons tend to make higher oxidation states more accessible. For these lighter actinide elements, the problem of assignment of electrons to 5f or 6d orbitals is difficult, since here the energy separations apparently lie within the range of chemical binding energies. It may not be possible to establish from the configuration of the gaseous atom the electronic structure of the compounds or of hydrated ions in aqueous solution. In the case of the lanthanide elements, the configuration of the gaseous atom includes, in general, only two electrons (beyond the xenon structure) outside the 4f shell, although the predominant oxidation state in aqueous solution is the trivalent state. It may also be noted that for a given element in the actinide group there is a stabilization of 5f compared to 6d electrons with increasing oxidation state.

However, the differences between the actinide and lanthanide groups give opportunities for the investigation of important new chemical phenomena. For example, their energetic position and larger spatial extension make the 5f orbitals available in bond hybridization; this leads to some very interesting complex ions. Similarly, the exposure of the 5f electrons can lead to field-splitting effects which can affect ionic entropies in

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manners which have not been observed in the lighter elements.

FUTURE DEVELOPMENTS

The discovery of further new transuranium elements seems possible. Studies of the known isotopes of the transuranium elements have made possible the prediction of the decay properties of new isotopes. For decay by both alpha-particle emission and spontaneous fission, the regularities have been found to be greatest for nuclei which contain an even number of neutrons and an even number of protons, thus making predictions of the properties for undiscovered isotopes of this type more certain. The rates of decay by alpha-particle emission and by spontaneous fission are slower for isotopes having an odd number of protons or an odd number of neutrons or an odd number of both protons and neutrons. Unfortunately for the prospect of producing ever higher elements, the predictions suggest shorter half-lives as atomic number increases. By the time elements 104 and 105 are reached, we shall probably find that the longest-lived isotopes that can be made will exist barely long enough for chemical identification. In the case of element 104, the predicted half-lives of the longest-lived isotopes are measured in seconds or minutes and for element 105 in seconds. It should be mentioned, however, that any of these nuclides can have a specially hindered decay, leading to longer half-lives than those predicted. It is likely that the present basic criterion for the discovery of a new element, namely chemical identification and separation from all previously known elements, will have to be changed at some point. Careful measurements of decay properties and production yields and mechanisms, and the clever use of recoil techniques, should eventually allow the extension of effective identification to another half-dozen elements or so beyond the heaviest now known. In fact the identification of the first isotopes of all the new elements that will be discovered in the future probably will be accomplished through the use of such methods, and the production of isotopes with sufficiently long half-lives to allow chemical identification will follow later. For the isotopes with very short half-lives, some chemical identification can probably be made using simpler and faster methods involving migration, volatility, reactions with surfaces, or gas-flow reactions.

Some interesting predictions concerning superheavy nuclei have been made. J. A. Wheeler has been able to show that extra-nuclear electrons for atoms with atomic number substantially higher than 137 (often considered the upper limit) would behave normally because of the finite extension of the nucleus. Accordingly it would appear that there is no limitation on the existence of such heavy elements from the standpoint of the electronic structure of such atoms. The production of such nuclei would require extremely high neutron fluxes, of the order of 10^{31} neutrons per square centimetre per second, such as may be present in stars. It is difficult to see how such nuclei can be made on earth. There is no indication that such superheavy nuclei can be produced and detected, because the rate of decay increases rapidly as the atomic number increases. Unless unexpected islands of stability due to closed neutron or proton shells are found, predictions based on regularities in decay properties suggest that it should not be possible to produce and detect elements beyond another half-dozen or so.

The prediction of the chemical properties of elements beyond mendelevium seems to be quite straightforward. Element 103 should complete the actinide series, and it is expected that elements 104, 105, 106, etc., will be fitted into the Periodic Table under hafnium, tantalum, tungsten, etc. The filling of the 6d electronic shell should be followed by the addition of electrons to the 7p shell, with the attainment of the rare gas structure at hypothetical element 118. It seems quite certain that the chemical identification of elements 102 and 103 will eventually be made by ion exchange, using knowledge of their homologues ytterbium and lutetium and other actinide elements. Element 102 might be expected to have a stable trivalent oxidation state and a somewhat unstable bivalent state which may be of importance in the chemical identification of the element. The bivalent state of element 102, if it is comparable in stability to the bivalent state of ytterbium, may permit a rapid separation of element 102 from the other actinide elements by electrolytic or amalgam reduction using ytterbium as a carrier. The stability of the bivalent state may be reflected in the properties of the metallic state of the element, resulting in an unusually low density and a relatively high volatility. Element 103 might be expected to have only a trivalent oxidation state. Element 104 should be exclusively tetravalent in aqueous solution and should resemble its homologue hafnium. Element 105 should resemble niobium and tantalum, and to some extent protoactinium, with the pentavalent oxidation state expected to be the most important.

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The chemical properties of element 106 can be predicted from those of tungsten, molybdenum, and to some extent chromium; thus we might expect to find the III, IV, V, and VI oxidation states. Elements 107, 108, 109, 110, etc., would be expected to have chemical resemblance to rhenium, osmium, iridium, and platinum respectively.

The possibility of preparing transfermium elements by the process of multiple neutron capture as a result of intense neutron bombardment over long periods of time is almost precluded by the fact that some of the intermediate isotopes have half-lives so short as to prohibit their presence in such appreciable concentrations as are required. Fortunately, there is another type of nuclear reaction that offers promise for the production of elements of higher atomic number than those now known. This is the method of bombardment with heavy ions. Reactions of this type have already been observed in many laboratories; isotopes of californium, einsteinium, and fermium have been produced by the bombardment of uranium with carbon ions, nitrogen ions, and oxygen ions, respectively. These ions can be accelerated in conventional cyclotrons. A linear accelerator capable of producing substantial beams of all the heavy ions up to neon and, possibly, usable beams of ions as heavy as those of argon has been constructed at the University of California at Berkeley. A similar accelerator is in operation at Yale University. Russia has shown a great interest in heavy ions and their application to the synthesis of transuranium elements and has accelerators for heavy ions under construction. Even with use of heavy ions, however, the source of target materials will present serious problems. New, expensive, high-flux reactors, producing 10^{15} to 10^{16} neutrons per square centimetre per second are needed in order to prepare even milligram amounts of berkelium, californium, and einsteinium within a reasonable space of time.

This short article has, of necessity, omitted even reference to many of the important aspects of the transuranium element field. In particular, it has not been possible to capture the international flavour of the work which has gone on in recent years. The emphasis has been on the chemical properties, the historical aspects, and the possibilities for future advances in this field. Much of interest could be told of the methods of production and of the many new long-lived isotopes which are becoming available in weighable amounts. The nuclear properties, which were barely mentioned, are of great interest. Over 80 isotopes of the transuranium elements are now known. The decay properties of these have been of great importance for the development of the Copenhagen school's unified model of the nucleus, and the induced and spontaneous fission properties of such isotopes are very important to the future development of a satisfactory theory for the nuclear fission process.

BIBLIOGRAPHY

KATZ, J. J. and SEABORG, G. T. 'The Chemistry of the Actinide Elements'. Methuen & Co. Ltd, London; John Wiley & Sons Inc., New York. 1957.

SEABORG, G. T. 'The Transuranium Elements'. Yale University Press, New Haven. 1958.

SEABORG, G. T. and KATZ, J. J. (Editors). 'The Actinide Elements', National Nuclear Energy Series, Div. IV, Vol. 14A. McGraw-Hill Book Co. Inc., New York. 1954.

SEABORG, G. T., KATZ, J. J., and MANNING, W. M. (Editors). 'The Transuranium Elements: Research Papers', National Nuclear Energy Series, Div. IV, Vol. 14B. McGraw-Hill Book Co. Inc., New York. 1949.

'Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955', Vols. I–XVI. United Nations, New York. 1956.

REMY, H. 'Treatise on Inorganic Chemistry', Vol. II. Elsevier Publishing Co., London. 1956.

HAÏSSINSKY, M. 'La chimie nucléaire et ses applications'. Masson et Cie, Paris. 1957.

BRUNI, G. 'Chimica Generale e Inorganica' (tenth edition). G. R. Levi and M. A. Rollier (Editors). Cesare Tamburini, Milan. 1957.

HYDE, E. K. and SEABORG, G. T. 'The Transuranium Elements'. Handbuch der Physik, Vol. XLII, p. 205. Springer-Verlag, Berlin. 1957.

PERLMAN, I. and RASMUSSEN, J. O. 'Alpha Radioactivity'. Handbuch der Physik, Vol. XLII, p. 109. Springer-Verlag, Berlin. 1957.

LISTER, M. W. 'Chemistry of the Transuranic Elements', Vol. IV, p. 20. Chemical Society, London. 1950.

NAST, R. and VON KRAKKAY, T. *Fortschr. Chem. Forsch.*, 2, 484, 1952.

MELANDER, L. *Svensk kem. Tidskr.*, 63, 311, 1951.

GOL'DANSKII, V. I. Новые Химические Элементы (New Chemical Elements). Ser. III, No. 2. Издательство 'Знание', Moscow. 1955.

SEABORG, G. T. 'The Eight New Synthetic Elements'. *Kagaku*, 19, 211, 1949.

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Doppler and the Doppler effect

E. N. DA C. ANDRADE

The Doppler effect is today applied in themes ranging from aerial navigation to the expanding universe. This article describes the origin of the principle, which was first put forward with astronomical application in view, its history and present employment.

Doppler is a name known today in one connection only, that of the Doppler effect. In the case of certain other men of science, notably Hooke and Boyle, the laws that bear their name represent but a very small part of their achievement: Doppler, however, although a very diligent worker, contributed nothing else to science that is remembered or deserves to be remembered, if we except possibly an early paper on the stroboscopic effect. Today his effect, or principle, has very wide and important applications, to which reference will be made later, but, although his account of it was published in 1843[1], the full significance was slow to be realized. For instance, it was not held to be of sufficient importance to be mentioned in the well-known history of physics published by Heller in 1882–84.

Christian Doppler, the son of a master stonemason, was born in Salzburg on 29th November 1805. He had apparently some talent as a carver, but was not of sufficiently strong build to follow his father's craft. The mathematician Stampfer recognized the lad's ability, and as a result he was sent to study at the Polytechnic Institute in Vienna. Later he taught mathematics in a subordinate position, and, failing to get a good post, was in 1835 on the point of emigrating to America when he was appointed professor of mathematics at the *Realschule* in Prague. Later he went to the Prague Technical College as professor of 'elementary mathematics and practical geometry'; and it was while holding this post that he published his famous principle. His next position was as professor of mathematics, physics, and mechanics at the Mining Academy at Schemnitz. About this time he was beginning to be recognized as a man of distinction and was given an honorary doctorate by the University of Prague. A little later he went back to Vienna and in 1850 was made professor of experimental physics at the university there, which was the goal of his ambitions. His institute was the first to be founded in Austria for the study of physics. He did not long enjoy the position, however, for he died of lung trouble in 1853. It will be seen that he had a very varied career as a teacher and only towards the end of his life obtained an office of academic distinction.

He was, it appears, a man of upright and attractive character. On the hundredth anniversary of his birth, when his principle had proved its importance, he was awarded various posthumous honours in Salzburg, Prague, and Vienna, even having streets named after him in the two latter cities. In 1901 a bust of him was set up in the University of Vienna (figure 1). On what records of his appearance it was founded is unknown to the writer.

The paper in which Doppler established the principle by which his name lives appeared in the *Abhandlungen der Königlichen Böhmischen Gesellschaft der Wissenschaften* (Proceedings of the Royal Bohemian Society of Learning) in 1843, under the title *Ueber das farbige Licht der Doppelsterne* (On the coloured light of the double stars) [1]. The subtitle says that it is an attempt at a theory which includes Bradley's theorem of aberration. The main object is, then, to deal with the way in which the velocity of a moving source of light should affect the frequency as perceived by an observer: in fact Doppler states explicitly towards the end of his discussion that the purpose of the paper was to demonstrate not the possibility, but the necessity, of an influence of the very high velocities of the heavenly bodies on the colour and intensity of their light as observed by us.

Doppler begins by speaking of the triumphs of the transverse wave theory of light, referring to the fact—somewhat surprising to us—that at the time, 1842, there were still physicists who were not convinced of its validity. Colour depends on the frequency of the pulsations stimulating the eye, and anything that changes the interval between successive impulses changes the colour perceived. As long as source and observer are at rest the frequency observed is the frequency of the light emitted by the source, but if the observer is moving

[1] Almost invariably quoted as 1842. The paper was read on 25th May 1842 but was not published until 1843.

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towards the source the frequency must increase, and if he is moving away from it, decrease. There must be similar effects if the source moves. Doppler says that at first hearing this may seem a purely academic distinction but that the honoured reader of what follows shall decide for himself. Whenever the velocity of source or observer is appreciable compared with that of the wave motion in its medium the effect is significant. Throughout he assumes that the waves (light waves in particular) are travelling in a medium through which the source and observer move freely, for which reason he refers more than once to Bradley's aberration. He uses, for instance, as an analogy a ship moving to meet or to retreat from a train of ocean waves.

He then considers the simple mathematical theory of the phenomenon and deduces, in a rather clumsy form, the equivalent of

$$n' = n\frac{c-u}{c-v}$$

where n is the frequency of the source, n' the frequency as appreciated by the observer, and c, u, and v are respectively the velocity of the wave in a stationary medium and the velocities of observer and source with respect to this medium, velocities being taken as positive when in the direction in which the wave is travelling.

FIGURE 1 – *Bust of Doppler.*

This formula can be simply derived by considering that the wavelength λ in the medium must be $(c-v)/n$, since the number of waves in a length c of the stationary medium is in a length $c-v$ when the source is moving in the direction of travel of the wave. The number n' of waves passing the observer per second is $(c-u)/\lambda$, since u/λ represents the number which do not reach the observer owing to his motion. Hence

$$n' = \frac{c-u}{\lambda} = n\frac{c-u}{c-v}$$

If u and v are small compared to c the magnitude of the effect depends only on the relative velocity of source and observer, and not on which of them moves relatively to the medium, since, if x is small, $1-x = 1/(1+x)$ approximately. If, however, u and/or v are large compared to c it makes a considerable difference, as can easily be seen by contemplating the case where u or $v = c$. If the source is moving in the direction of the wave motion, $n' = \infty$; if the source is moving in the opposite direction, $n' = \frac{1}{2}n$; if the observer is moving in the direction of the wave motion, $n' = 0$; if in the opposite direction, $n' = 2n$.

To return to Doppler's paper: after establishing the formula he takes sound as an example and shows that to raise the pitch of a note from C to D the observer must move towards the source with a velocity of about 136 ft/sec. A velocity of 8 ft/sec should be sufficient to produce a perceptible effect; but, says Doppler, 'I will now proceed to my true object and apply these considerations to light.'

The whole continuous spectrum will be shifted towards the blue if the source approaches us, towards the red if it recedes; and to make a body emitting white or violet light invisible the source will have to recede from us with a velocity of $19/42 = 0{\cdot}45$ that of light. This false conclusion is based on a fallacy which pervades the whole of Doppler's discussion of the changes of colour of moving stars. Knowing, apparently, nothing of the effects which had been already found beyond the red and beyond the violet by F. W. Herschel and by J. W. Ritter respectively, he believed the spectrum to be a band of frequencies terminating at the red and violet, so that a suitable receding motion of the source would shift, for example, the violet to the blue, where the observed spectrum would end. If the velocity were sufficient to shift the violet to just beyond the red, no light at all would be perceived by the observer. To obtain the velocity just quoted he took as the frequency of the extreme red and as that of the extreme violet figures not very different from those of Thomas Young [2].

Arguing on the basis of a limited spectrum and considering the relative brightness of different parts of the continuous spectrum, Doppler concluded that, with a source of white light, such as he considered all stars to be, a velocity of 33

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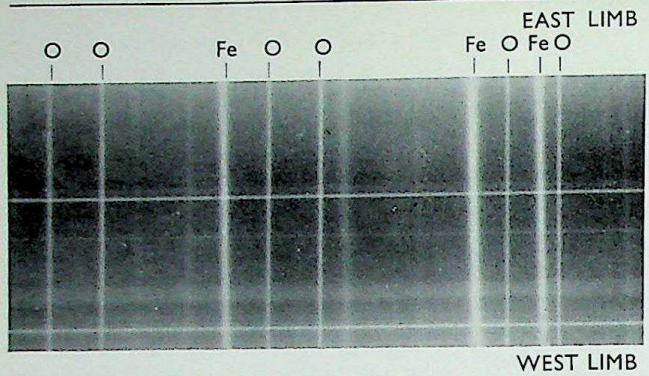

FIGURE 2 – *Doppler effect due to the Sun's rotation. The sharp absorption lines* (O) *are due to oxygen in the Earth's atmosphere and so show no effect. The lines* (Fe) *due to iron in the Sun's photosphere are displaced to the violet at the east limb of the Sun, which is approaching us, and to the red at the west limb, and so are sloped with reference to the oxygen lines.* (*By courtesy of H. H. Plaskett.*)

Austrian miles (152 English miles) per second towards or away from the observer would produce a change in colour perceptible to the eye. A velocity of 860 English miles per second would produce a strong change in colour. Stars with line of sight velocities, then, of from 152 to 84 000 miles per second should show changes of colour, the more notable the greater the velocity: with higher velocities still they should become invisible.

Doppler then produces nine arguments from astronomical observation as examples of the effect of stellar velocities on colour, invoking both double stars and variable stars. For instance, he says that with double stars where one component is much larger than the other the major star is nearly always white, the minor coloured: when the two components are about equal, both are coloured, one pertaining to the short-wave half of the spectrum, the other to the long-wave half. He also states that, in the fifty years separating the observations of Herschel the elder from those of Struve, the colours of the double stars γ Leonis and γ Delphini changed. All such matters, and even the occurrence of new and the vanishing of old stars, he attributes to velocity effects. Needless to say, none of the effects arose from the cause to which he attributed it. His general argument and his enunciation of the Doppler principle were correct, and the effect in the case of sound which he adduced as an illustration was correct, but the particular phenomena of stellar colour to explain which his whole effort was directed have nothing to do with the Doppler effect.

Tyndall in his celebrated book 'Sound', first published in 1867, after describing the mechanism of the Doppler effect for sound, says 'This is the basis of Doppler's theory of the coloured stars. He supposes that all stars are white, but that some of them are rapidly retreating from us, thereby lengthening their luminous waves and becoming red: others are rapidly approaching us, thereby shortening their waves, and becoming green and blue. The ingenuity of this theory is extreme, but its correctness is more than doubtful.'

The validity of even the general principle was not universally accepted by men of science, the chief antagonist being Petzval, celebrated for his work on lenses, whose opposition, based upon a misunderstanding of the problem, began in 1852 and continued for some years. The effect was soon verified in the case of sound, first of all, in 1845, by Buys-Ballot [3], who used an open carriage pulled by a locomotive along a straight stretch of railway to carry his moving source or observer. The source was trumpets blown by skilled players, the observers trained musicians who estimated the changes of pitch by ear. He used both trumpets in the car and observers by the side of the track, and observers in the car and trumpets by the side of the track. Needless to say, the noise of the locomotive caused some trouble, but the results agreed with the theory as well as could be expected. Incidentally, Buys-Ballot put forward criticisms of Doppler's assertion that the eye could detect differences of colour due to the movements of stars, to which Doppler replied. Acoustic experiments on the same lines were carried out in England by Scott Russell in 1848 [4]. More accurate were the tests made by H. C. Vogel in 1876 [5], using a locomotive with a whistle that gave a particularly pure tone. The notes of the approaching and of the receding whistle were matched on a violin.

Fizeau [6], to whose important paper later reference will be made, devised an ingenious laboratory experiment to demonstrate the effect. A wheel 1 metre in diameter carried a card fixed radially, and teeth on a short arc were arranged, above and below, so as to be struck by the card when the wheel rotated. Thus the card, when set in vibration by one set of teeth, constituted an approaching source to an observer in the plane of the wheel's rotation and, when set in vibration by the other set, a receding source. In this way the experimenter obtained differences of tone of a major third (ratio 5 : 4), which agreed very well with the value calculated from the velocity.

A simple demonstration devised by K. R. König [7] about 1865 is of interest as illustrating the method of a very recent application of the effect with radio waves, to be mentioned later.

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Two similar tuning forks were adjusted to give four beats a second when sounded together. If one remained stationary while the other was moved at uniform speed towards the ear, the number of beats changed, increasing or decreasing according as the moving fork was the graver or the acuter of the two. The point is that with this method of beats, which is so sensitive to frequency changes, a velocity very small compared with the wave velocity is sufficient to give a detectable effect. With König's forks, of frequency 512, a velocity of 2 ft/sec gave a change of one beat per second: with a frequency of 1024, 1 ft/sec would have sufficed to produce such a change. The higher the frequency, the smaller the velocity, relative to the wave velocity, that can be detected.

Laboratory demonstration of the effect with light is, of course, much more difficult than with sound, but was carried out by Belopolski about 1900 [8]. He took advantage of the fact that, with multiple reflection of light from a source between two approximately parallel mirrors, the effect of the velocity of each mirror is multiplied n times at the nth reflection. Two wheels were used, rotating in opposite senses, each carrying a number of radially mounted mirrors, the number merely serving to increase the intensity. The Fraunhofer lines of sunlight were taken as the standard frequencies to be modified by reflection at the moving mirrors. With the radius in question (about 22 cm) and the speed of rotation (about 44 revolutions per second) four reflections, occasionally six, could be effectively used. Fair agreement with theory was obtained. In the repetition of the experiment, with better spectroscopy, carried out by Prince Galitzin and J. Wilip in 1907 [9], the observed displacement of the mercury lines which they used agreed within 5 per cent with that calculated from Doppler's formula. Majorana, using a modified wheel apparatus of the same type, verified the principle with somewhat greater accuracy in 1918.

The Doppler effect for light was established in the laboratory in a less troublesome manner by Fabry and Buisson in 1919 [10]. They used a disk of white paper, only 16 cm in diameter, which rotated about a vertical axis at approximately 200 turns per second, so that the diametral velocity was only a third of a millionth of that of light. The light sources were two spots, at opposite ends of a fixed diameter, illuminated by a mercury lamp. Observation was made in a direction normal to the line joining the bright spots and very oblique to the plane of the disk, so that the sources were small and bright and the full velocity was effective. The difference of frequency of the light from the approaching and from the receding spot was measured by means of the Fabry-Perot interferometer, thanks to the sensitiveness of which the experimenters were able to verify the effect within an accuracy of 3 per cent—an extraordinary feat with such low velocities.

So much for the experimental establishment of the effect. Of prime importance for the applications to astronomy was a paper by Fizeau, whose name is known to all physicists for his measurements of the velocity of light. It was read to the *Société Philomathique* in 1848 but was, however, not published in full until 1870 [6]. It contains an account of the sound experiment already mentioned. Proceeding to consider the case of light, Fizeau proposes that sharp spectral lines should be used to give the frequencies whose modification is to be measured and suggests that their deviation should be observed with a prismatic spectroscope. He calculates that for a line in the region of sodium D a velocity equal to that of Venus should produce a deviation of 2·65″, which can be doubled by turning the prism through 180°, and specifically says that the radial velocity of distant stars could be measured in this way. He goes into the practical difficulties: the light of the star being feeble, a prism covering the whole objective would be needed, and it is difficult to get so large a prism homogeneous. He concludes '*Il est donc permis d'espérer que ce genre d'observation sera possible et que l'expérience pourra prononcer sur la réalité des phénomènes indiqués.*' This clearly foreshadows the correct method of applying the effect to astronomy, in contrast to Doppler's impossible contentions. Fizeau makes no mention of Doppler. Incidentally, Belopolski and others call the law in question the Doppler-Fizeau principle.

The first practical astronomical applications were published in 1868 by Sir William Huggins [11]. After consulting Clerk Maxwell he made measurements on Sirius, selected as the brightest star in the heavens, using the F line of hydrogen, from the displacement of which he deduced a recession at about 29 miles per second. This was before the application of photography to spectroscopy, the position of the line being taken with a micrometer. In the following year he measured in the same way the radial velocities of several other stars, some approaching, and others receding from, the Sun. The measurements were not, in the light of modern work, particularly accurate, but were of importance as establishing the method. The first really reliable results were obtained by

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H. C. Vogel [12] in 1888, using the photographic method. Since then striking improvements in the telescope, the spectroscope, and the photographic plate have made it possible to work with much greater accuracy, and velocities of 1 km/sec can be measured. The radial motion of several thousand stars has been recorded. The Doppler shift to the red in the spectra of nebulae has been much studied as evidence for an expanding universe. In the case of the remotest observed nebulae the velocity of recession somewhat exceeds one-fifth that of light, so that the change of wavelength exceeds 20 per cent, corresponding to a marked change of colour such as Doppler originally anticipated for his stars.

The effect has also been applied to the rotation of the Sun (figure 2). The spectral lines in light from the eastern limb of the Sun are found to be displaced towards the violet as compared with those from the western limb, which is clearly the consequence of a rotation such as makes the eastern limb approach the Earth, the western limb recede. The shift is very small, the difference between the light of eastern and of western origin being only about 1/75 000 of the wavelength of the line used, which corresponds to a velocity of approach and recession of about a mile and a quarter per second, or one rotation in about 25 days (figure 2). The intensity of the solar light permits greater dispersion than is possible with stellar light, so that considerable precision is possible. The rotation has been measured in various latitudes, with very interesting results. The rotation of the rings of Saturn and of various planets has also been measured by the same general method.

Reference must further be made to binary stars whose nature has been revealed by the Doppler effect in the light from the two components which are too close to be resolved telescopically. It is clear that the periodic variations of the Doppler displacements give the period of these stars, the so-called spectroscopic binaries. The first to be announced was discovered by E. C. Pickering [13] in 1889, namely Mizar (ζ Ursae Majoris). The period was 104 days. Today thousands of spectroscopic binaries are known, some with periods of less than a day. Enough, perhaps, has been said to indicate the great part played by the Doppler effect in modern astronomy.

An important terrestrial application of the Doppler principle with light was demonstrated in 1905 by Johannes Stark [14], when he obtained the effect with canal rays (positive rays) in a hydrogen discharge tube. He found that with observation normal to the direction of the rays the Balmer lines of the hydrogen spectrum had their normal frequency and character: if, however, observation were made from a position such that the rays were travelling towards the spectroscope, the lines were broadened towards the violet, while if observation were made from the opposed direction, there was a broadening towards the red. The general effect, then, corresponded to what was to be expected if the moving particles were radiating the lines, the continuous nature of the broadening being due to the fact that, owing to collisions, the light-emitters had all possible velocities up to the maximum. The extent of the broadening enables the maximum velocity of the luminous particles to be determined, which is less than that calculated from the applied potential on the supposition that unhindered acceleration takes place. The Doppler effect is pronounced, since it is easy to obtain in the discharge tube velocities of some thousandths of that of light.

Much work was carried out by Stark and others, notably Rau, on this effect with various gases, work which was, at the time, very important for the evidence which it supplied as to the electrical state of the atoms emitting arc and spark spectral lines and of the molecules emitting band spectra. When Stark was awarded the Nobel Prize in 1919 the main reference in the citation was to his 'epoch-making' investigations of the Doppler effect with canal rays, the Stark effect being mentioned as supplementary.

In any luminous gas, ordinary thermal agitation means that the atoms or molecules concerned in the emission are moving in all directions and should therefore show a Doppler effect manifesting itself as a broadening of the line in question, symmetrically, since as many sources are approaching as are receding. The effect should, however, be very small, since, for instance, the average velocity of a hydrogen atom at 100° C is about a hundred-thousandth of that of light. As a precise measure of the effect, what is termed the half-intensity breadth is used. As an example of the magnitude, for a sodium D line at 300° C this Doppler broadening is about 0·02 Å, or 1/300th of the distance between the D lines. This is easily measured with modern spectroscopic technique. On account of the smaller atomic weight the hydrogen lines under like conditions are broader. For very accurate spectroscopic work these lines have been made sharper by working with the discharge tube in liquid air. At the other extreme, the Doppler broadening has come into prominence in

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connection with the famous ZETA, where it has been used to estimate the temperature in the discharge [15]. The breadth of the lines as measured here is in the region of 1 Å.

In a completely different field, the Doppler effect has recently been applied with great success to aerial navigation, where a main problem has always been to measure ground speed. The older types of instrument give speed with reference to the air, and, the local wind speed being frequently not known with any great precision, fail to provide accurately the desired location. König's tuning fork experiment, where a movement with a speed a thousandth of that of sound altered the beat frequency perceptibly, supplies the principle. Suppose that an aircraft sends out two beams of radio waves, one forward and one backward, directed downward sufficiently to be reflected (or, more correctly speaking, scattered) back to the source from the ground at not too great a distance. The Doppler effect due to the moving source will make the frequency of the reflected forward beam a little higher, that of the reflected backward beam a little lower, than that of the emitted wave, the magnitude of the change of frequency being proportional to the speed of the aircraft. These two slightly different frequencies, received by the aircraft, will produce by their interaction a comparatively low frequency oscillation. By modern methods of instrumentation, involving a phonic wheel, the periodicity of this low-frequency oscillation strictly controls the speed of revolution of a motor, which, by further ingenious mechanism, is made to furnish the pilot with direct reading of the ground speed and the distance flown. To measure the drift the two beams are swung so that one goes down to port, the other to starboard, the information being made available in a like manner.

A numerical example may be helpful. In an actual Marconi installation the frequency of the emitted wave is 8800 Mc/s. Since reflection is in question, the effect due to the movement of the aircraft, which is both source and receiver, is doubled. On the other hand, if the beam is directed downwards at 60° to the horizontal, which is about the angle used, the velocity of the aircraft, flying horizontally, resolved along the beam is halved, so that all that need be considered is the normal effect due to a source moving in line with a stationary receiver. If the velocity of the aircraft is 335 m.p.h., which is about a two millionth of that of light, the increase of frequency of the reflected forward beam will be 8800/2 = 4400 c/s, and the decrease of frequency of the reflected backward beam will be 4400 c/s, so that the beat frequency will be 8800 c/s, that of a high audible note, about five octaves above the middle C. This is low enough to control the speed of rotation of the motor that works the gear.

A last instance of present-day applications is the use of the Doppler effect to track artificial satellites circling the earth. The transmitter carried by the satellite sends out a continuous wave of fixed frequency, the modifications of which, as detected by the observer, are used in the manner recently described in ENDEAVOUR [16].

The history of the principle is, then, a strange one. It was put forward over a hundred years ago by Doppler with the sole object of explaining the colour of stars, but the deductions from observational evidence which he marshalled to support it were completely erroneous. Some decades later it was proved to have astronomical applications of importance, which increased as time went on, and in recent times it has risen to the position of providing the main observational evidence for an expanding universe. In textbooks of physics it is mainly handled in connection with sound, of which aspect daily life provides many examples. In the last year or so it has played a part in the astonishing attempts to demonstrate a nuclear fusion reaction, in advancing aerial navigation, and in tracking man-launched satellites. The modest Austrian would be astonished to see the scope and importance of work which in his lifetime aroused but little attention.

REFERENCES

[1] DOPPLER, C. *Abh. Böhm. Wiss.* (V), **2**, 465, 1843.
[2] YOUNG, T. *Phil. Trans. roy. Soc.*, **92**, 12, 1802.
[3] BUYS-BALLOT, C. H. D. *Pogg. Ann.*, **66**, 321, 1845.
[4] RUSSELL, J. S. *Brit. Assn. Rep.*, **18**, 37, 1848.
[5] VOGEL, H. C. *Pogg. Ann.*, **158**, 287, 1876.
[6] FIZEAU, H. *Ann. Chim.* (*Phys.*) (IV), **19**, 211, 1870.
[7] KÖNIG, K. R. 'Catalogue des appareils d'acoustique'. Paris, 1865.
[8] BELOPOLSKI, A. *Astrophys. J.*, **13**, 15, 1901; *Bull. Acad. Sci. St. Péters.*, **13**, 462, 1900.
[9] GALITZIN, B. and WILIP, J. *Astrophys. J.*, **26**, 49, 1907.
[10] FABRY, C. and BUISSON, H. *J. Phys.*, **9**, 243, 1919.
[11] HUGGINS, W. *Phil. Trans. roy. Soc.*, **158**, 529, 1868.
[12] VOGEL, H. C. *Astr. Nachr.*, **119**, 97, 1888.
[13] PICKERING, E. C. *Amer. J. Sci.*, **39**, 46, 1889.
[14] STARK, J. *Phys. Z.*, **6**, 893, 1905.
[15] ALLEN, J. E. *Endeavour*, **17**, 117, 1958.
[16] BURT, E. G. C. *Ibid.*, **17**, 216, 1958.

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The surfaces of plants

B. E. JUNIPER

The wettability of leaf surfaces varies from plant to plant and has considerable practical importance—the efficiency of chemicals applied to leaves may ultimately depend on it. New techniques in electron microscopy have made it possible to resolve the ultra-structure which largely determines wettability, and the techniques and results are discussed here.

Interest in the behaviour of liquids on leaves was stimulated by the increasing use of sprays in agriculture and particularly by the discovery of weed-killers of the growth-regulator type. The differences in susceptibility to these hormonal weed-killers may be due to some plants shedding the droplets from their surfaces and thus failing to absorb them. This may be caused by the posture of the leaves, their shape, or the unwettability of the surface.

The degree of wettability may be measured by the angle of contact between the liquid-air surface and the solid. The wettability of a solid by a liquid is dependent on the interaction between the liquid molecules and the chemical groups exposed on the solid surface, and also on the texture of that surface [1]. The highest contact angle for a plane surface of a naturally occurring substance is probably not above 105°. However, many plants have apparent contact angles on their leaves and other surfaces far above this figure. The angle may vary considerably from one part of the plant to another and may also be subject to diurnal changes, as shown by G. E. Fogg [2].

A few of these high values are due to macroscopic or microscopic morphology, as in *Juncus inflexus*, which has a smooth waxy cuticle folded into ridges, or as in *Salvina*, which has curious micro-projections on the leaf surface.

In the majority of species the surface roughness responsible for the high contact angle lies beyond the resolution of the microscope, and attempts have been made to utilize the electron microscope. The low penetrating power of the electron beam prevents its being used for the direct observation of a surface. An attempt to circumvent this by using reflection electron microscopy was made on insect cuticle [3]. However, the usefulness of this technique is limited by the resolution being only a little above that of the light microscope, and by the severe distortion of the image which makes interpretation difficult. The problem of looking at so solid an object as a leaf in the electron microscope can be obviated by using a surface replica. A negative mould of the surface is made of a material that is transparent and inert in the electron beam. This may be viewed directly (the negative replica) or a cast may be made of this negative replica, of the thickness required, and this positive replica examined in the microscope. There are a number of materials that can be used to make surface replicas, including certain plastics [4, 5].

This technique necessitates wetting the leaf surface. This can be avoided by using evaporated carbon as the replica material [6]. Carbon is completely inert, is non-crystalline, can replicate detail down to the 1 mμ level, and, unlike conventional plastics, can replicate biologically 'moist' surfaces. Either a pseudo-replica or a true replica is produced. In the first instance, parts of the original surface remain embedded in the carbon layer (figures 1 and 3); in the latter (figure 2) a true replica consisting of carbon only is formed. Either picture can easily be interpreted.

The replicas reveal minute projections from the surface of the cuticle in many plants. These projections are assumed to be of wax extruded through the cuticle. They are of many different forms and may be characteristic of the species, the genus, or even the family; but although A. de Bary [7], as early as 1871, grouped the types of wax structures to be found on leaves, no classification yet seems to be possible with this technique. All the forms of *Brassica oleracea* look very much alike (figure 1). The garden pea (figure 21) resembles the white lupin (figure 4), but so also does the quite unrelated *Galanthus nivalis*, the snowdrop (figure 9). *Chrysanthemum segetum* (figure 3), on the other hand, looks totally unlike any other species of *Chrysanthemum*.

The surface ultrastructure is not necessarily the same all over the plant. Figures 21, 11, and 12 show the adaxial, abaxial, and stem surfaces of a

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FIGURE 1 – *Adaxial surface of* Brassica oleracea var. capitata.

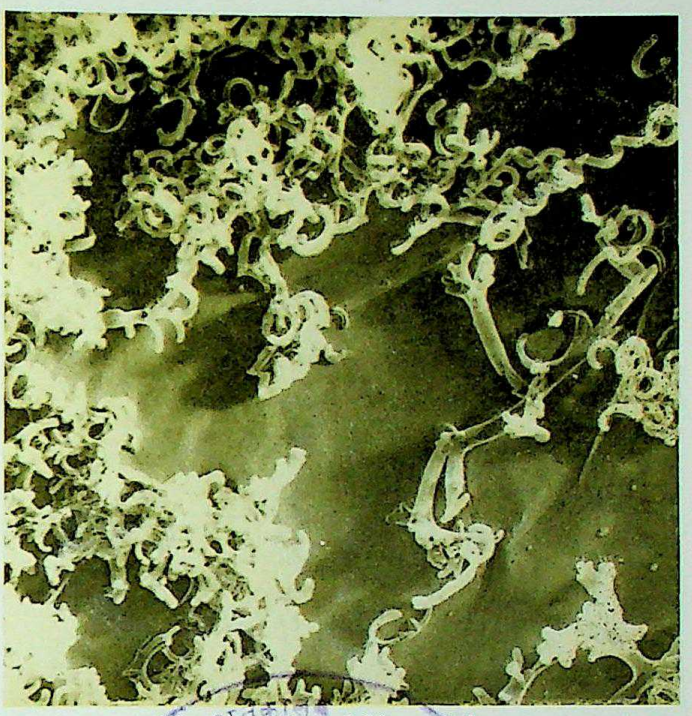

FIGURE 3 – *Adaxial surface of* Chrysanthemum segetum.

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FIGURE 2 – *Adaxial surface of* Hyacinthus orientalis.

FIGURE 4 – *Adaxial surface of* Lupinus albus.

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Carbon replicas of leaf surfaces × 10 850.

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FIGURE 5 – *Adaxial leaf surface of* Kleinia articulata.

FIGURE 8 – *Stem surface of* Kleinia articulata.

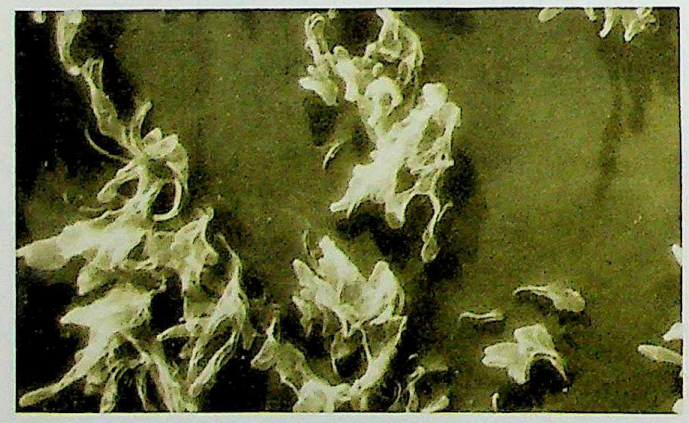

FIGURE 6 – *As above, after one second's immersion in distilled water.*

FIGURE 9 – *Adaxial leaf surface of* Galanthus nivalis.

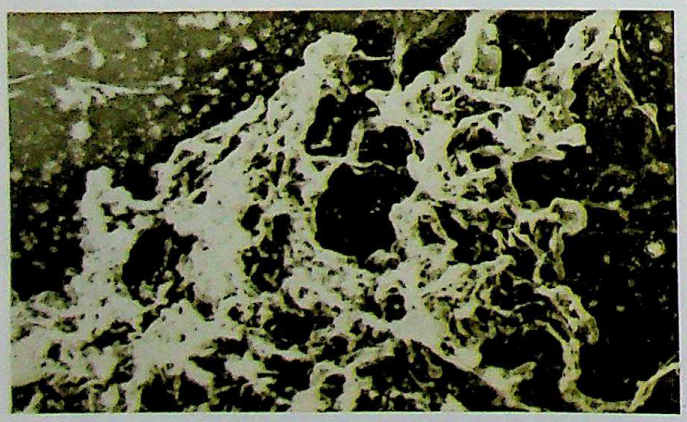

FIGURE 7 – *As above, after ten seconds' immersion in distilled water.*

ACKNOWLEDGMENTS

I am grateful to Miss Joan Sampson for taking the electron micrographs and to Sir Paul Fildes, F.R.S., for electron microscope facilities in the Sir William Dunn School of Pathology, Oxford.

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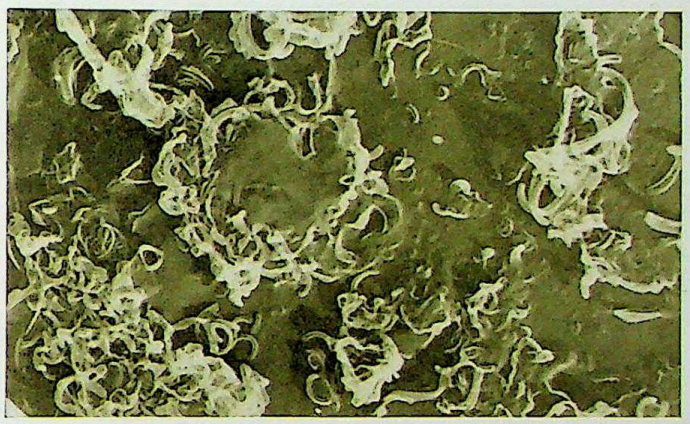
FIGURE 10 – *Adaxial leaf surface of* Bryophyllum tubiflorum.

FIGURE 13 – *Adaxial leaf surface of* Lupinus albus (*folded replica*).



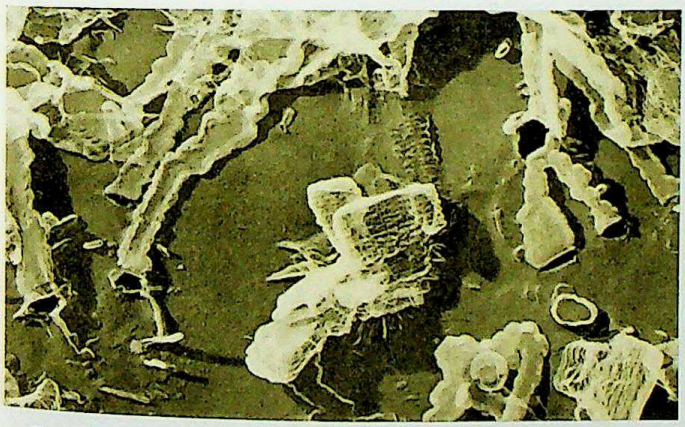


FIGURE 11 – *Abaxial leaf surface of* Pisum sativum.

FIGURES 14 (*upper*) *and* 15 – *Adaxial leaf surfaces of* Chrysanthemum segetum *immediately after brushing and seven days later respectively.*

FIGURE 12 – *Stem surface of* Pisum sativum.

FIGURE 16 – *Adaxial surface of* Pisum sativum *grown in wind tunnel at* 25 *m.p.h. wind speed.*

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Figure 17

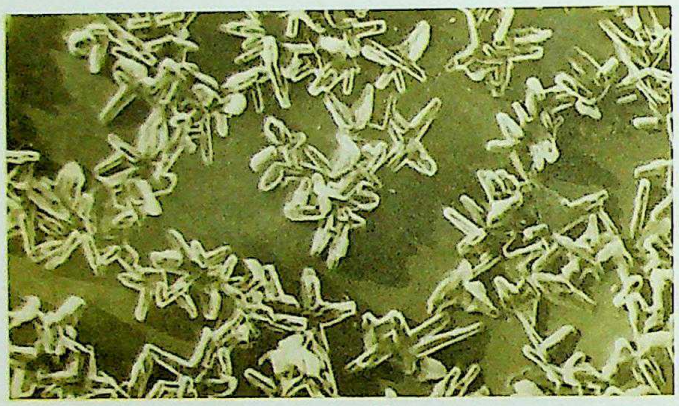

Figure 18

Figure 19

Figure 20

FIGURES 17–20 – Pisum sativum *grown in darkness to second leaf stage. Fig. 17: 24 hours after transfer to light. Fig. 18: 48 hours after transfer. Fig. 19: 72 hours after transfer. Fig. 20: 7 days after transfer.*

Figure 21

Figure 22

Figure 23

Figure 24

FIGURES 21–24 – Pisum sativum. *Fig. 21: grown at 5000 ft.candles light intensity. Fig. 22: at 1500 ft.candles. Fig. 23: at 900 ft.candles. Fig. 24: grown in darkness.*

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pea, and figures 5 and 8 the leaf and stem surfaces of *Kleinia articulata*. As a general rule the cotyledonary leaves are smooth even in plants which have a highly complex surface structure on other organs. The high degree of resistance to weed-killers possessed by *Chrysanthemum segetum* may be due to the occurrence of wax projections over all aerial parts of the plant, including cotyledons, petioles, stems, and both leaf surfaces. A further factor may be its ability to recover from mechanical damage. Figure 14 shows an adaxial surface immediately after brushing. Figure 15 shows a corresponding leaf seven days after similar treatment, when the wax projections have regenerated.

Under field conditions surfaces are not usually damaged so severely. Surfaces such as those represented in figures 3, 4, and 21 are moderately or extremely resistant to weathering, and the leaves maintain high contact angles until senescence. On the other hand, surfaces like those in figures 1, 2, 5, and 10 are very easily damaged and may only remain unwettable for a few days. The cause is usually simple mechanical damage such as breaking off or flattening of the minute projections, but figures 6 and 7 show the effect of immersing a leaf of *Kleinia articulata* in distilled water for one second and ten seconds respectively. The surfaces of the other plants illustrated do not seem to be affected in this way by water. The indirect effect of other environmental changes may be just as striking. Figures 21–24 show the effect of reducing the intensity of light falling on the leaf surfaces of peas. The contact angle falls with the decrease in surface wax development, and this may assist in explaining the increased susceptibility of weeds growing under crops and sprayed after harvesting. Another change due to the environment is that leaves subjected to high wind speeds seem to develop a more dense and compact layer of wax projections. (Compare figure 16 with figure 21.)

A number of compounds, e.g. trichloracetic acid, are used in agriculture for treatment of the soil before germination and increase the susceptibility of some weeds to herbicides. Under the electron microscope it is seen that the wax projections are reduced progressively in size with increasing concentration of treatment and present a surface which is less water-repellent [8].

The method of development of these projections is difficult to understand. A number of surfaces have projections with an annular sculpturing suggesting some form of phasic growth (figures 1 and 11). Since it is impossible to make replicas of leaves smaller than about 3 mm, a study of the development of the surface from the primordial stage is not yet possible. The youngest leaves that can be studied have surfaces similar to those of mature leaves. To gather some idea of the course of development of the wax, peas can be grown in darkness to the second leaf stage. In darkness no wax projections are formed at all, but they develop quite rapidly after transfer to the light (figures 17–20). The transition from one stage to another is difficult to explain, because we must presume a continuous reorganization of the surface. Moreover no pores or apertures from which projections such as those in figures 2 or 8 could be derived have ever been resolved, and they must have been extruded as liquids.

There is a complete agreement between the occurrence of such projections on the surfaces as seen under the electron microscope and contact angles above 105° recorded on those surfaces, although for the reasons given these high values may not be permanent. An impression of a transverse section of a leaf at this level of resolution is given in figure 13. In this instance the carbon film has bent over and has been photographed at right angles to the normal plane of viewing, giving a transverse view. This shows how a droplet must be held away from the cell wall by the projections.

The view that everything external to the epidermal cells is static can, on the present evidence, no longer be held. We must presume that since the density of projections on the very young leaves is the same and not higher than that on the mature leaves, production of surface wax continues until leaf expansion has ceased. This, and the evidence of recovery from mechanical damage and changes to environmental conditions, indicate that there must be a continuous passage of substances through the cuticular layers.

REFERENCES

[1] ADAM, N. K. *Endeavour*, 17, 37, 1958.
[2] FOGG, G. E. *Proc. roy. Soc., B*, 134, 503, 1947.
[3] HOLDGATE, M. W., MENTER, J. W., and SEAL, M. Proceedings of the International Conference on Electron Microscopy, London. 1954.
[4] MUELLER, L. E., CARR, P. H., and LOOMIS, W. E. *Amer. J. Bot.*, 41, 7, 1954.
[5] SCHIEFERSTEIN, R. H. and LOOMIS, W. E. *Plant Physiol.*, 31, 3, 1956.
[6] BRADLEY, D. E. *Brit. J. appl. Phys.*, 5, 65, 1954.
[7] DE BARY, A. *Bot. Ztg*, 29, 9, 10, 1871.
[8] JUNIPER, B. E. *New Phytol.* (In press.)

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Palaeomagnetism and ancient wind directions

N. D. OPDYKE and S. K. RUNCORN

Study of the direction of magnetization of rocks shows that the continents have changed their distances from and their orientations relative to the geographical pole. It is very desirable to confirm the positions revealed by this work. One method is to use the record of the directions of the trade winds of ancient geological times as preserved in aeolian sandstones. The methods used in both of these approaches, and the extent to which they confirm one another, are discussed with reference to both hemispheres in this article.

In a previous article in ENDEAVOUR, S. K. Runcorn [1] described the developments in the study of rock magnetism that have been made in recent years. Strong evidence was advanced that about the time of their formation certain igneous rocks, mainly lavas, and some sediments, mainly red sandstones, acquired a magnetization which has remained substantially unchanged. The magnetization of a rock series of a particular geological age shows a remarkable consistency even over hundreds of miles, and there is reason to believe that this remanent magnetization represents the mean direction of the geomagnetic field at that time, allowance having been made for any tilt the rocks have acquired since formation. It was found that in Great Britain, where a widespread survey of this type was first made, that there has been a gradual change of the mean direction of the field through geological time and that only in Cainozoic times (the last sixty million years) does this mean direction coincide with a field symmetrical about the present axis of rotation of the earth.

The earth's magnetic field today is nearly, but not exactly, the same as would be produced by a small, powerful magnet or 'dipole' at the earth's centre orientated with its axis coincident with the geographical axis. From historical observations it is known that the field changes irregularly, and from these observations alone one would suspect that the mean field over a time of the order of a thousand years would be much more nearly that of an axial dipole than is the field at the present time: the theory of the geomagnetic field gives strong support to this supposition. Consequently it is possible to determine from the mean direction of magnetization of a rock formation, sampled over a sufficient thickness to remove the effects of this 'secular variation', the positions of the poles with respect to the site during the corresponding geological time.

The determination of the pole position is a very important step in rock magnetism studies, and it is desirable to explain in more detail how this is done. Figure 1 shows the direction of the field at the surface of the earth due to a dipole at the geocentre. The angle of inclination is the angle made by the direction of the field with the horizontal and varies from zero at the equator to a right angle at the pole. A simple formula relates the angle of inclination to the latitude (λ). A great circle through the direction of magnetization of the rock, after correction for geological tilt,

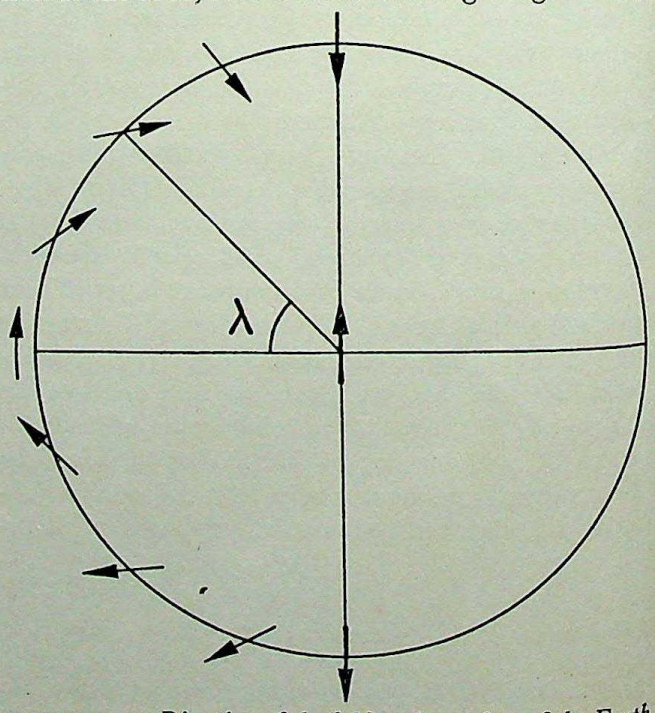

FIGURE 1 – *Direction of the field at the surface of the Earth due to a dipole at the centre. (From 'Geomagnetism', Vol. 1, by S. Chapman and J. Bartels, p.105. Oxford University Press, 1940.)*

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is constructed. From the latitude the position of the pole on this great circle is easily determined.

The survey of the palaeomagnetic directions for different geological ages and different continents has now advanced considerably. When the article referred to [1] was written it had been shown that the pole positions in successive geological periods for Great Britain lie on a reasonably smooth curve and that they lie successively nearer the present pole as the age of the period diminishes. This may be interpreted either as a motion of Great Britain relative to the rest of the earth or as a movement of the axis of rotation relative to the earth. The latter, termed polar wandering, would probably have occurred if internal motions had taken place in the earth's mantle and if the spheroidal shape of the earth could have changed, over periods of the order of millions of years, into shapes appropriate to the new positions of the axis of rotation. Thus at first it appeared possible that the rock magnetism results could be explained by polar wandering alone.

The polar wandering curves derived from other continents should in this case have been in agreement. Although that for North America was similar in shape to that for Europe, Runcorn [2] showed that the American curve lay significantly west of the European one, as shown in figure 3 [3]. Consequently it appears that late in Mesozoic times North America moved about 20° west relative to Europe. Such relative movement of the continents, presumably involving the basaltic floor of the oceans, is postulated in a theory known as continental drift which some geologists advanced long ago.

Recently E. Irving and R. Green [4] have shown that the polar wandering curve for Australia lies almost as far away as it possibly could from the polar wandering curves for North America and Europe. This curve lies across North Africa and joins the present pole from the North Atlantic. Both of these surprising discrepancies are more acceptable when it is noted that, in general, the palaeomagnetic results from a continent give values of its latitude at the time of the formation of the rocks, which latitude, unlike the present latitudes, shows no conflict with the palaeoclimatic indications obtained from geology. In Australia, for example, Irving and Green find (figure 2) that at the times when the position of Australia, inferred from the palaeomagnetic data, was near the pole in the Permo-Carboniferous and the late Pre-Cambrian, geological evidence indicates that Australia suffered widespread glaciations. Similarly the great deserts of late Palaeozoic and early Mesozoic times in North America and in North Europe are paralleled in the palaeomagnetic evidence by nearly horizontal magnetizations, from which a position close to the equator is inferred (figure 13).

It may be asked whether it is possible to show that the directions of the magnetic field deduced from the palaeomagnetic measurements are consistent over very considerable areas. Not as many relevant measurements are available as one would like. Almost every rock formation that has yet been studied extends over hundreds of miles, and there is certainly persistence over this range in the palaeomagnetic directions. It is much more interesting, however, to consider whether the palaeomagnetic measurements of rock formations of the same age across an entire continent indicate the same place for the poles. In this connection it must be noted that the polar wandering curve indicates a movement of the pole of about one-third of a degree per million years, and consequently during a geological period it is quite possible that the pole motion (apart from the secular variation, which is assumed to be smoothed out in all cases) could lead to differences of up to 20 or 30 degrees in the palaeomagnetic directions of rocks of the same geological period. Unfortunately the rocks that have been used so far in palaeomagnetic studies are those in which fossils are most scarce, and consequently the determination of their geological age to any time very much shorter than a geological period seems difficult. However, the Upper Triassic of the United States furnishes an example of good agreement between pole positions deduced from widely different areas, as shown in figure 14.

It will be seen that the basic claim made in the interpretation of rock magnetism studies is that palaeomagnetism provides a method of directly establishing the latitude of a site at the time of formation of its rocks. The test of the reliability of rock magnetism methods depends on finding independent methods of determining latitudes in remote geological times. The study of palaeoclimates is the most obvious method.

Now movement of the earth's axis of rotation relative to the land masses will cause different parts of the latter to fall in the trade wind belt. Fortunately sand dunes and aeolian sandstones can in fact be used to show the direction of modern and ancient winds respectively.

SAND DUNES

It is known [5] that barchan dunes are formed

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Palaeomagnetism and ancient wind directions

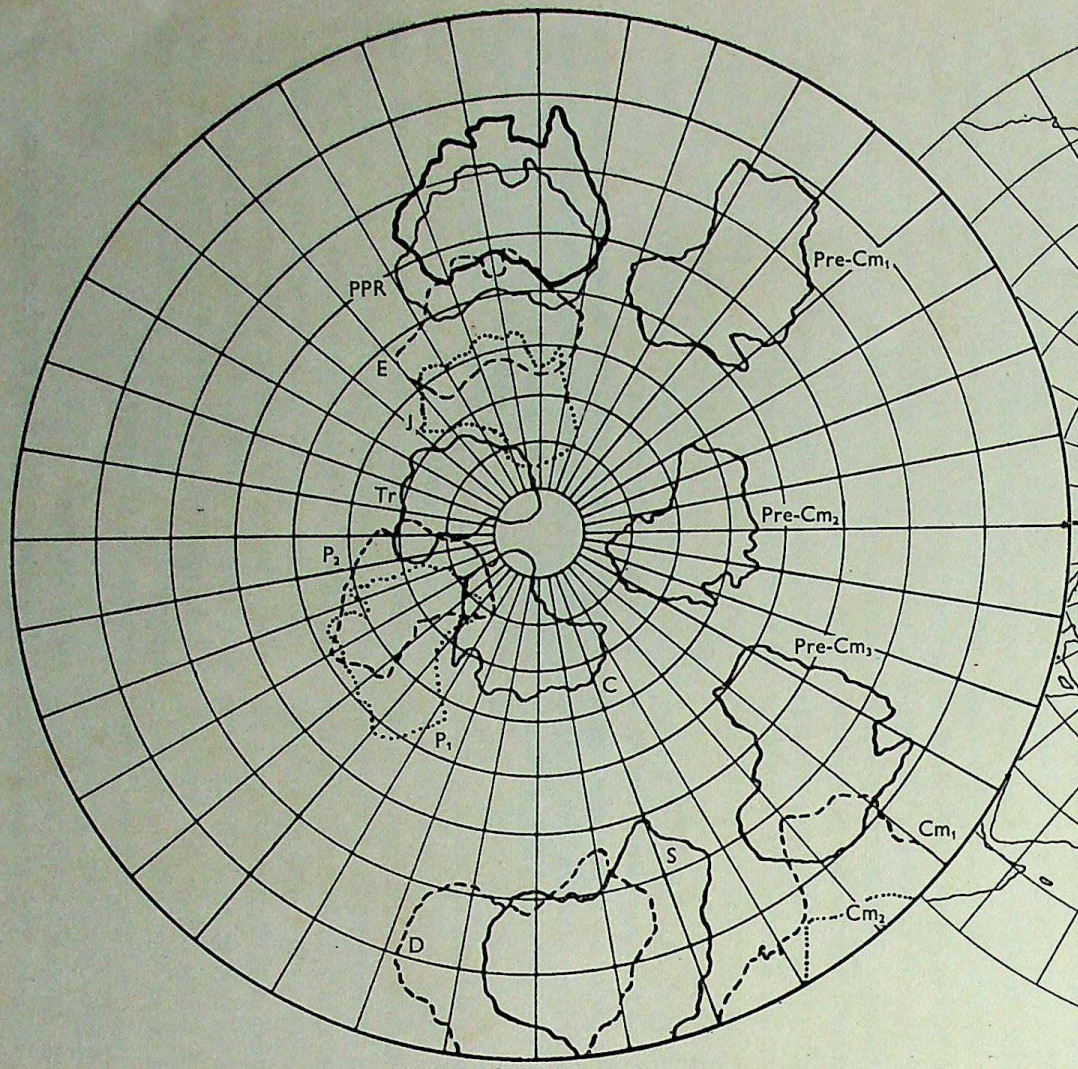

FIGURE 2 – *Positions of Australia relative to the South Pole at various geological times, as deduced from palaeomagnetic evidence. Heavy outline denotes present position of Australia. After Creer, K. M., Irving, E., Nairn, A. E. M., and Runcorn, S. K.* Ann. Géophys., 14, 492, 1958.

PPR	*Pliocene, Pleistocene, and recent*	D	*Devonian, probably Lower Devonian*
E	*Lower Tertiary, probably Eocene*	S	*Upper Silurian*
J	*Mesozoic, probably Jurassic*	Cm_2	*Middle Cambrian*
Tr	*Triassic, probably lower Triassic*	Cm_1	*Lower Cambrian*
P_2	*Permian, Upper Marine Series*	$Pre\text{-}Cm_3$	*Top of Upper Proterozoic*
P_1	*Permian, Lower Marine Series*	$Pre\text{-}Cm_2$	*Upper Proterozoic*
[illegible]	[illegible]	$Pre\text{-}Cm_1$	*Lower part of Upper Proterozoic*

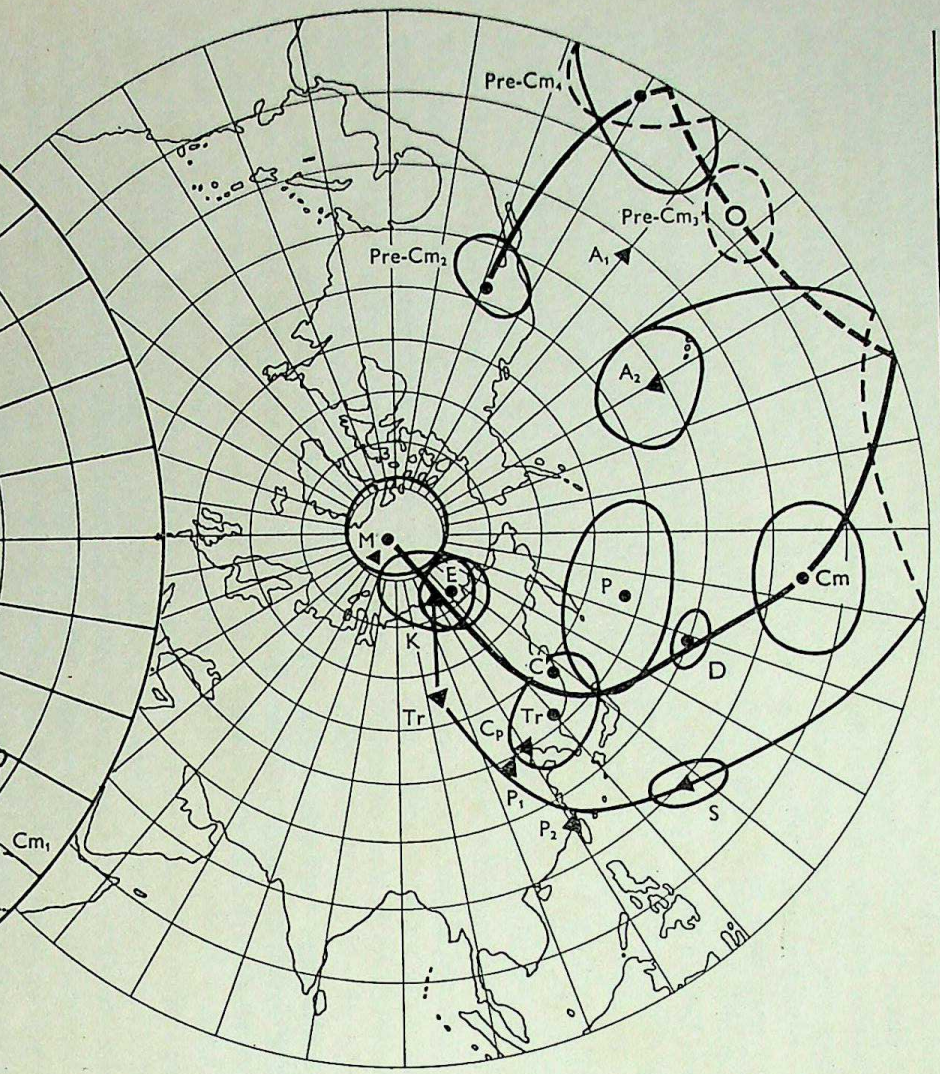

FIGURE 3 – *Polar wandering curves for North America and Europe* [3].

M	*Miocene*	C_p	*Carboniferous (Pennsylvanian)*
E	*Eocene*	D	*Devonian*
K	*Cretaceous*	S	*Silurian*
Tr	*Triassic*	Cm	*Cambrian*
P	*Permian*	Pre-Cm	*Pre-Cambrian*
C	*Carboniferous*	A	*Pre-Cambrian (Algonkian)*

Triangles denote poles determined from measurements on American rocks. Full dots denote poles determined from measurements on British rocks. (Open circle denotes a pole on the other hemisphere.) Thin line denotes approximate path of the pole based on American rocks. Thick line denotes approximate path of the pole based on British rocks. (Dotted lines denote paths drawn on the other hemisphere).

The ovals in this figure and in figure 14 are 95 per cent confidence limits.

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FIGURE 4 – *Sand dune near Kayenta, Arizona.*

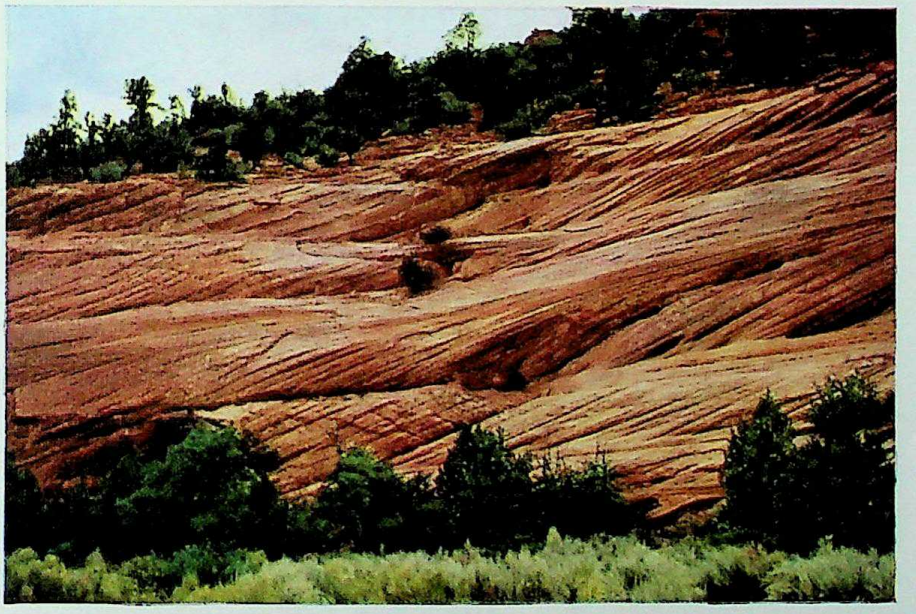
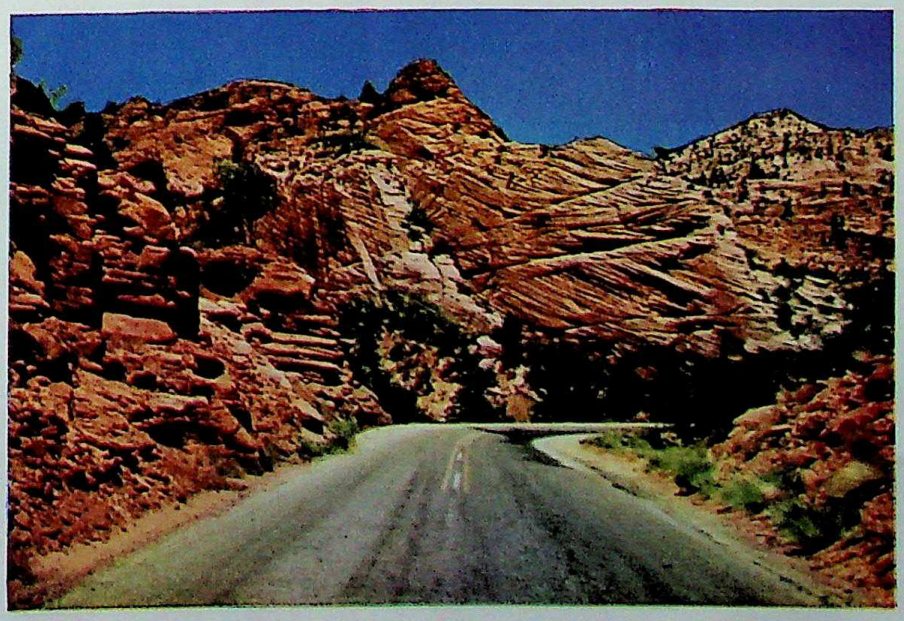


FIGURE 5 (*above*) – *Wingate sandstone (Triassic age), Colorado River Valley, near Moab, Utah.*

FIGURE 6 – *Navajo sandstone (Jurassic age), Mount Carmel Highway, Zion National Park, Utah.*



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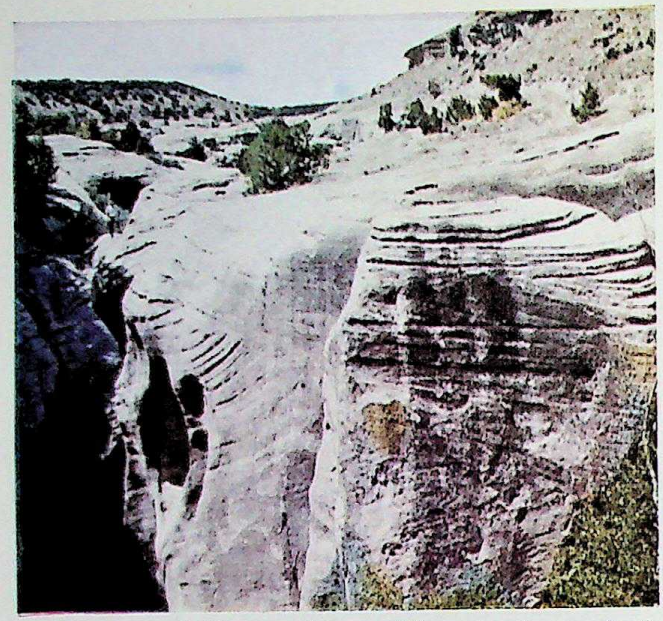

FIGURE 7 – *Weber sandstones (Pennsylvanian age) in Brush Creek Canyon, south flank of the Uintah Mountains, Utah. The height of the man in the left background conveys an idea of the scale.*

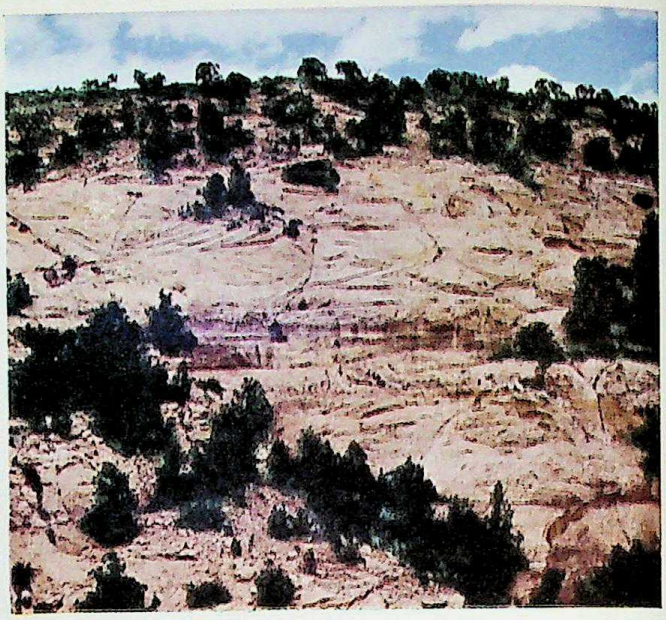

FIGURE 8 – *Weber sandstone (Pennsylvanian age) in Sand Canyon, Dinosaur National Monument, Utah.*

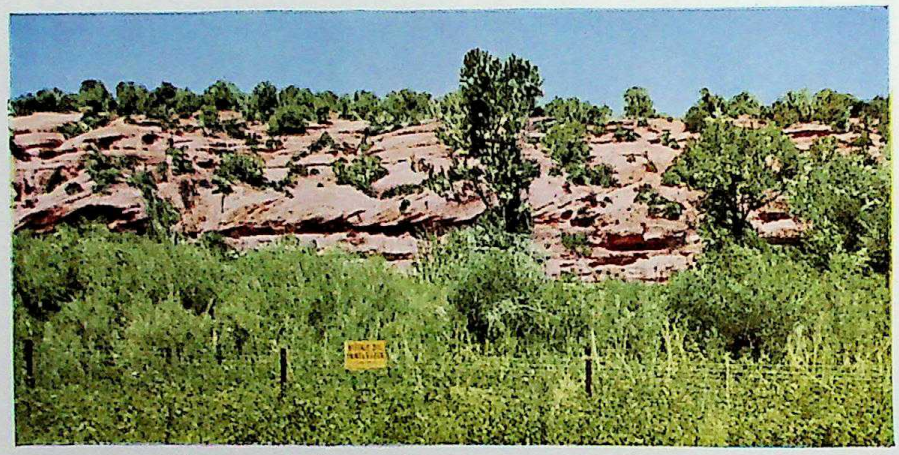

FIGURE 9 – *Tensleep sandstone (Pennsylvanian age) in Tensleep Canyon, Wyoming. Photograph taken from the east. Note that the lee slopes dip towards the south, indicating that the wind blew from the north.*

FIGURE 10 – *Sand dunes near Kanab, Utah.*

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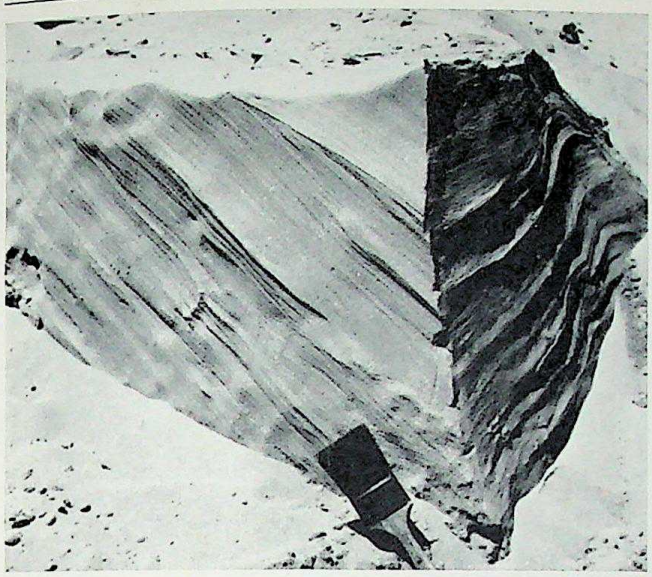

FIGURE 11 – *Vertical cut through sand dune at Leupp, Arizona (after McKee). The paint-brush gives some indication of the size of the section.*

by steady winds of constant direction in deserts in which the supply of sand is limited. A photograph of one of nearly perfect form is shown in figure 4. The windward slope to the right is a gentle one from which sand is being continually blown, deposition occurring on the steep lee-side slopes. These are crescent-shaped in plan, with the points downwind. On these steep slopes the sand rests at its angle of repose, which is about 33°. The barchan is the simplest form, and where there is more sand transverse dunes are formed. These consist of a sinuous line of steep lee slopes, parts of which resemble barchans. An example is shown in figure 10.

Successive layers of sand deposited on these lee slopes differ slightly in packing or size distribution or in the colour of the sand grains. Thus if a vertical cut is made through a sand dune, traces of these 'bedding planes' may be observed. E. D. McKee [6] has made such observations on a sand dune in Arizona, and figure 11 is taken from his paper.

Similar sand seas to these have become fossilized in the past and are preserved in the geological record as aeolian sandstones. In these sandstones traces of the bedding surfaces on the lee slope remain and can be observed in exposures of the rock made naturally by erosion, or artificially in quarries and in road or rail cuts. It is possible to measure the azimuth and the angle of dip of the line of greatest slope of parts of these bedding planes. The average of the azimuths gives the mean direction of movement of the sand dunes and hence the wind direction. The scatter of the directions depends on the curvature of the lee slopes of the dunes and on the variation of the wind direction.

The process by which a sea of dunes gets preserved is similar to that of any sedimentary deposit, i.e. the lowering of the land relative to sea level and subsequent deposition of marine beds. The sand will become cemented by silica-bearing or carbonate-bearing solutions permeating through it millions of years after its initial deposition. Cycles of wind erosion may occur while the dunes are still exposed and they may be planed down to a nearly flat surface on which later dunes can accumulate. Such presumed erosion surfaces are shown in figure 5 by the well-marked horizontal lines.

In an exposure of aeolian sandstone it is rare to see a large part of a single dune. Usually the vertical face of rock reveals sections through a number of dunes, each at different angles to the lee slope. The trace of the parallel bedding planes from any one dune is known as a cross-bedded unit. Examples of these are shown in figures 5–9.

Unfortunately there is at the present time no simple diagnostic test that can be applied to a sandstone which enables the geologist to distinguish with certainty between an aqueous and an aeolian environment of deposition. But if the following criteria are all satisfied a strong case exists for inferring aeolian deposition:

1. Highly inclined cross-bedding up to the angle of rest of dry sand (33°) occurring in very large units, some of which exceed 50 ft in height (see for example figure 7). Similar cross-bedded structures can be produced by deposition in streams and in the sea as a result of strong currents, but they are usually much smaller in size than dunes and have smaller angles of bedding.

2. The absence, due to winnowing by the wind, of micaceous material. This is due to the fissile nature of these minerals, which causes them to break on impact.

3. The absence of marine fossils, which indicates continental deposition.

4. High coefficients of sorting and roundness, due to the sand's mode of transport. Very small grains of sand will be transported much further than very large grains, and so in any particular dune, grains of one size will predominate. Frequent impacts will round off the grains.

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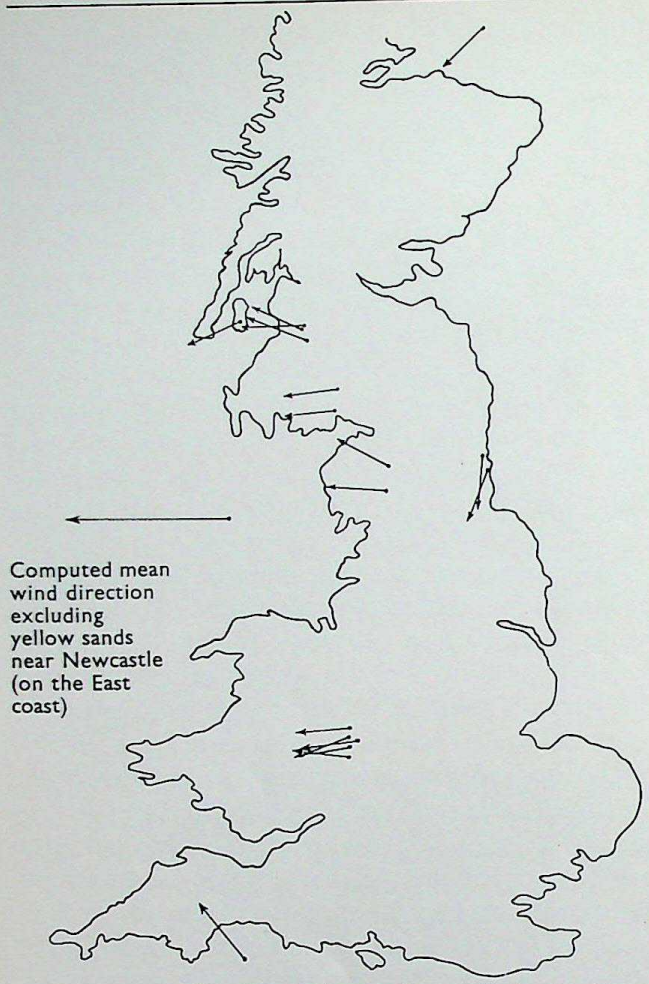

FIGURE 12 – *Directions of prevalent winds in Great Britain for Permian times (after Shotton* [8] *and Opdyke).*

FIGURE 13 – *Directions of prevalent wind in Western United States for Permian and Pennsylvanian times. (Arizona results after Reiche* [10]*; other results after Opdyke and Runcorn,* Bull. Geol. Soc. Amer. *In the press.)*

The method used by geologists to determine the direction of movement of the sand dunes that form the aeolian deposits is a fairly simple one. A compass is placed on the bedding plane that was at one time the front slip face of the sand dune, and the direction of the normal to a level line on this slip face is recorded. This represents the direction in which a portion of the original dune face was moving. If from 30 to 100 of these readings are made, each from separate cross-bedded units, the movement of the sand dunes is obtained by representing each of the directions by an arrow and deriving, rectorially, the mean direction.

OBSERVATIONS IN BRITAIN AND NORTH AMERICA

Extensive palaeodeserts in the northern hemisphere at the end of the Palaeozoic period occurred in England (Triassic and Permian periods) and in the Western United States (Permian and Pennsylvanian periods). The age of these aeolian sandstones is thus 200–250 million years.

The palaeodesert of the Permian of England is typified by the Penrith sandstones of the Eden Valley. This formation was described by J. R. Dakyns, R. H. Tiddeman, and J. G. Goodchild [7]: 'Extended observations upon the directions of false-bedding in the rock show that there is a marked predominance of false-bedding planes inclined, in a general way, from some easterly point towards the west. On the assumption that the Penrith Sandstone is of aeolian origin, this westerly false-bedding may indicate the prevalent direction of the winds during the dry seasons.' More recently F. W. Shotton [8] compiled results from Permian aeolian sandstones from all over Great Britain, and he found that the wind that deposited these sandstones was an easterly wind which varied only slightly from the north of Scotland (Elgin) to the south of England (Devon). These are shown in figure 12.

In North America the Coconino sandstone of

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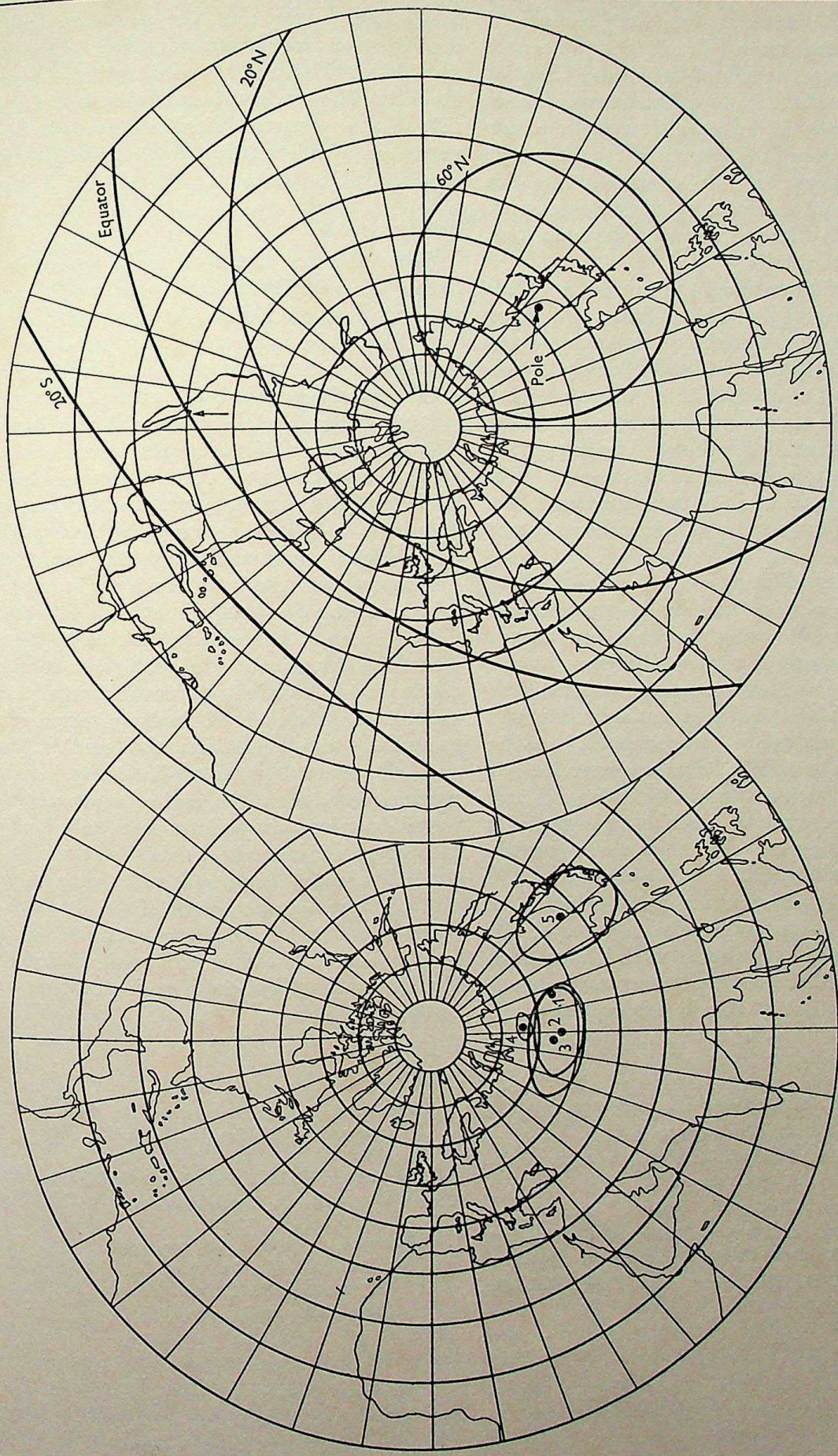

FIGURE 14 – *Upper Triassic pole positions deduced from palaeomagnetic observations at points in Great Britain and the United States.* 1, *Springdale Sandstone, Utah;* 2, *Lavas near Holyoke, Massachusetts;* 3, *Lavas and sediments of Connecticut;* 4, *Newark series, New Jersey;* 5, *Keuper Marls, England* [11].

FIGURE 15 – *Relative position of Europe and North America and positions of pole, equator,* 20°*N,* 20°*S, and* 60°*N latitude lines for late Palaeozoic and early Mesozoic times, deduced from palaeomagnetic observations.*

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Permian age of Arizona has long been recognized as an aeolian sandstone [9]. It is a prominent feature just below the rim of the Grand Canyon, where it is a 300 ft thick white deposit and extends as an easily recognized formation over hundreds of miles. P. Reiche [10] examined the directions of cross-laminations of this sandstone, and his results are plotted in figure 13: they show, apart from a few local variations, a remarkably consistent north-north-east wind.

The only other presumed palaeodeserts of the upper Palaeozoic of the United States that have been studied are slightly older than the sandstones of Arizona, being in the uppermost Pennsylvanian and very early Permian. These geologic formations, called the Tensleep, Casper, and Weber sandstone of Wyoming, south-west Wyoming, and Utah respectively, were studied by the authors in the summer of 1956, and it was again found that the direction of the wind was from the north-east (figure 13).

The possibility of tracing the direction of the wind through geological time by means of aeolian sandstones is an interesting project in itself, but it is at present important because it represents one of the few ways in which the determinations of the position of the pole in relation to the land masses through palaeomagnetic measurements can be independently checked. The palaeomagnetic evidence suggests that the western United States and Great Britain were much closer to the equator in Upper Palaeozoic times than they are at present. Figure 15 shows the position of the equator, 20°N, 20°S, and 60°N latitude lines and the poles for late Palaeozoic and early Mesozoic times. It will be seen that both these areas would have been within the wind belt of the northern trade winds if the present width of this belt is typical. It is interesting to see that the evidence from the aeolian sandstones described above supports this prediction. The easterly wind deduced from the Permian of Great Britain and from the late Palaeozoic of the western United States both become north-east winds relative to the position of the equator at that time.

CONCLUSION

There appears, therefore, to be agreement between the wind directions and palaeomagnetic pole positions for North America and Europe in late Palaeozoic and early Mesozoic times. The Botucatu sandstone of Upper Triassic Age of South America is now being studied.

If this promising line of research were extended into other areas of the world, particularly the aeolian sandstones of Africa (Forrest-Bushveld sandstone), the Triassic (perhaps Cretaceous) of Asia, and the possibly aeolian Nubian sandstone of the Middle East, much might be learned about the past patterns of the earth's general atmospheric circulation and climate. If it were possible eventually to read from the rocks the wind directions throughout the geological column in all continents it might be possible to determine whether the trade wind belts have varied in their latitudinal extent through the earth's history. As their extent depends on both the general climatic state of the earth and on its rotation, this would be a very important piece of geophysical evidence, for it is thought that the rotation of the earth has gradually slowed and that a thousand million years ago the length of the day was probably one sixth of the present length. Thus an indirect method of determining the speed of the Earth's rotation throughout geological time would be of great interest.

REFERENCES

[1] Runcorn, S. K. *Endeavour*, **14**, 152, 1955.

[2] *Idem*. *Proc. Geol. Ass. Canada*, **8**, 77, 1956.

[3] Creer, K. M., Irving, E., and Runcorn, S. K. *Phil. Trans., A*, **250**, 144, 1957.

[4] Irving, E. and Green, R. *Geophys. J.*, **1**, 64, 1958.

[5] Bagnold, R. A. 'Physics of blown sand and desert dunes.' Methuen & Co. Ltd, London. 1941.

[6] McKee, E. D. *Bull. Amer. Assoc. Petrol. Geol.*, **41**, 1704, 1957.

[7] Dakyns, J. R., Tiddeman, R. H., and Goodchild, J. G. *Mem. geol. Surv., U.K.*, Sheet 30, 110, 1897.

[8] Shotton, F. W. *Lpool Manchr Geol. J.*, **1**, 450, 1956.

[9] McKee, E. D. *Carnegie Inst. Wash. Publ.* No. 440, 77, 1934.

[10] Reiche, P. *J. Geol.*, **46**, 905, 1938.

[11] Du Bois, P. M., Irving, E., Opdyke, N. D., Runcorn, S. K., and Banks, M. R. *Nature, Lond.*, **180**, 1186, 1957.

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The planetarium

H. C. KING

For over two thousand years attempts have been made to illustrate by models or other devices various astronomical phenomena, such as the rising and setting of the celestial bodies, the sequence of day and night, eclipses of the Sun and Moon, and the motions of the planets. This article describes such models, from the early star globes, armillary spheres, and orreries to the modern projection planetarium, which embodies features from all three types.

The idea that the Earth is not a flat disk but a globe placed at the centre of the spherical vault of the heavens appears to have originated in the sixth and fifth centuries B.C. in ancient Greece, where men like Pythagoras and Plato fostered geometry and favoured a geometrical approach to natural phenomena. The sphere, they argued, is the most perfect of all geometrical forms; hence the Earth, no less than the vault of heaven, has a spherical shape. On this basis it became natural to represent the stars on globes, and this was done long before the construction of the first terrestrial globe. Men became familiar with the stars and grouped them in patterns to form constellations many centuries before they could map even the Old World with reasonable accuracy. On the one hand the nightly wheeling of the heavens brought the stars to recurrent appearance, the circumpolar stars in particular lending themselves most favourably to the idea that the stars are fixed like luminous studs to the surface of a rotating celestial sphere. On the other hand, the general acceptance of the idea of a spherical Earth and knowledge of the general distribution and shapes of its land masses had to await the great voyages of discovery of the fifteenth and sixteenth centuries.

One of the earliest star globes appears to have been that which the astronomer Eudoxus of Cnidos either made himself or brought out of Egypt about 370 B.C. A century later the Cilician poet Aratus composed his *Phaenomena*, a poem generally considered to be based on a description of the constellations according to Eudoxus. The earliest extant celestial globe (figure 1) also appears to have had some connection with Eudoxus, for the arrangement of the forty-two constellations sculptured in relief upon its surface suggests that it was probably constructed around 300 B.C. This marble globe, 26 inches in diameter, is supported on the broad shoulders of a statue of kneeling Atlas some six feet high. The entire sculpture is preserved in the National Museum of Naples and is known as the *Atlante Farnesiano*.

According to Cicero [1], C. Sulpicius Gallus, 'a very learned man', told him that Eudoxus adorned his celestial globe 'with the fixed stars of heaven, and with every ornament and embellishment'. Gallus also mentioned a mechanical model of the heavens which Marcellus had carried off from Syracuse in 212 B.C. as part of the spoils of war. It was made by Archimedes, who lost his life when the city was sacked, and the Romans so greatly admired the model heavens or planetarium that Marcellus placed it in the Temple of Virtus. Gallus described the planetarium as a kind of globe in which revolved models of the Sun, Moon, and the five naked-eye planets (then known as the seven wandering stars or planets), each model going through its 'unequal and varied movements' during 'one revolution of the machine'.

In all probability the planetarium of Archimedes was a spherical astrolabe or armillary sphere. In its most simple form the armillary sphere appears to have been used by Eratosthenes, Hipparchus, and other astronomers at Alexandria for the measurement of the positions of the Sun, Moon, and stars. It usually consisted of a group of three or more concentric and intersecting rings which were either mounted on a firm stand or suspended by cords from a ceiling. These rings represented in turn the horizon, meridian, celestial equator, and ecliptic, while an additional movable ring furnished with sights enabled an observer to measure the angular distance of the celestial object from any one of the reference circles. In the hands of the Muslims these armillae became most elaborate, and were used in western Europe for the teaching of astronomy until well into the eighteenth century. One development of the device was to fix a model Earth at the centre of the system of rings so that the instrument could be used to

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illustrate the geometry of the Ptolemaic, or Earth-centred, conception of the universe (figure 2). Another development was the flat or planispheric astrolabe, an instrument greatly appreciated and perfected by the Muslims, and one used as an aid to navigation up to the end of the eighteenth century.

The first departure from the idea of a star globe as a sphere having stars and constellation figures marked on its outer surface was made by Adam Oelschläger, or Olearius, court mathematician and librarian to Duke Frederick III of Holstein-Gottorp. Under his superintendence, during the years 1654–64, Andreas Busch of Limberg made a hollow copper sphere about 11 feet in diameter and some $3\frac{1}{2}$ tons in weight (figure 3). Through the sphere passed a solid metal axis supported at each end and inclined at $54\frac{1}{2}°$ to the horizon, this angle being the latitude of Gottorp. The outer surface of the sphere showed a map of the known world, and a wide horizontal circle enabled visitors to walk round the globe and examine the map in detail. In the southern part of the globe a small door gave admittance to the interior, which was illuminated by two small oil lamps [2]. Inside, the circular platform suspended from the axis held as many as ten spectators, and from this floor the operator slowly rotated the globe by turning the handle of an Archimedean screw. With the globe in motion a succession of gilded stars and constellation figures appeared to rise and set relative to an artificial horizon. The monthly change in the appearance of the night sky, the diurnal motion of the Sun, and the Sun's apparent motion along the ecliptic were also seen, the sun being represented by a glass sphere which could be given its own motion along the ring of the ecliptic. In 1715 the globe was sent as a present to Czar Peter the Great, who in turn presented it to the St Petersburg Academy of Sciences. According to a recent report it is now preserved in the Zoological Museum, Leningrad.

The next recorded celestial globe of this type was made by Erhard Weigel. In 1654 Weigel became professor of mathematics in the University of Jena and gave much thought to mechanical devices for popularizing astronomy. One of his star globes is now in the Museum of the Franklin Institute, Philadelphia. It is approximately 18 inches in diameter and has an unusual set of constellations, for Weigel changed many of the classical figures to represent the coats of arms of the ruling European families at that time. The stars are formed by little holes punched in the globe, and to see them in their constellations the observer looks into the globe's interior through a large hole.

The largest hollow celestial globe was that designed by Roger Long, Lowndes's Professor of Astronomy at Cambridge, and completed in 1758. Long arranged for the sphere, 18 feet in diameter and suitably inclined for the latitude of Cambridge, to be set up at Pembroke College. It could be rotated by a winch and rackwork, and the stars, as in Weigel's sphere, were represented by holes of various sizes pierced in the metal. As many as thirty visitors could stand inside and watch the rising and setting of the stars relative to an artificial horizon. Long hoped that his sphere would do much to popularize astronomy, but in this he was to be bitterly disappointed. Although he set aside £6 a year for maintenance, the sphere gradually fell into a state of disrepair. W. H. Smyth, writing about it in 1844, says that 'many a good man and true has lived and learned in Cambridge, without even being aware of its existence' [3].

Greater success attended the large star globe which W. W. Atwood designed in 1911 for the express purpose of providing instruction in the fundamentals of astronomy at the Chicago Academy of Sciences (figure 4). The globe was fifteen feet in diameter, made of thin galvanized sheet iron, and weighed no more than 500 lb [4]. It was supported at its equator by three wheels and could be turned by a small electric motor, rotating about an axis inclined at 41° 50′ to the horizontal. The stars were formed by numerous holes, all correctly graded in size and carefully positioned. A small electric light which could be moved along the ecliptic represented the Sun. For the Moon Atwood used one of several small disks cut to represent the phases of the Moon and coated with luminous paint. He even catered for the planets, demonstrating their wanderings among the stars by opening a series of apertures, but this arrangement does not appear to have been very successful.

After the sixteenth century the comparative geometrical simplicity of the Copernican system, compared with that of the Ptolemaic system, greatly aided the construction of models of the solar system. Yet while it was a fairly simple matter to devise a mechanism which would drive model planets in circular orbits with uniform motions about a central Sun, to drive them at approximately the correct proportional speeds with only a small number of simple gear-wheels presented considerable difficulty. The problem was

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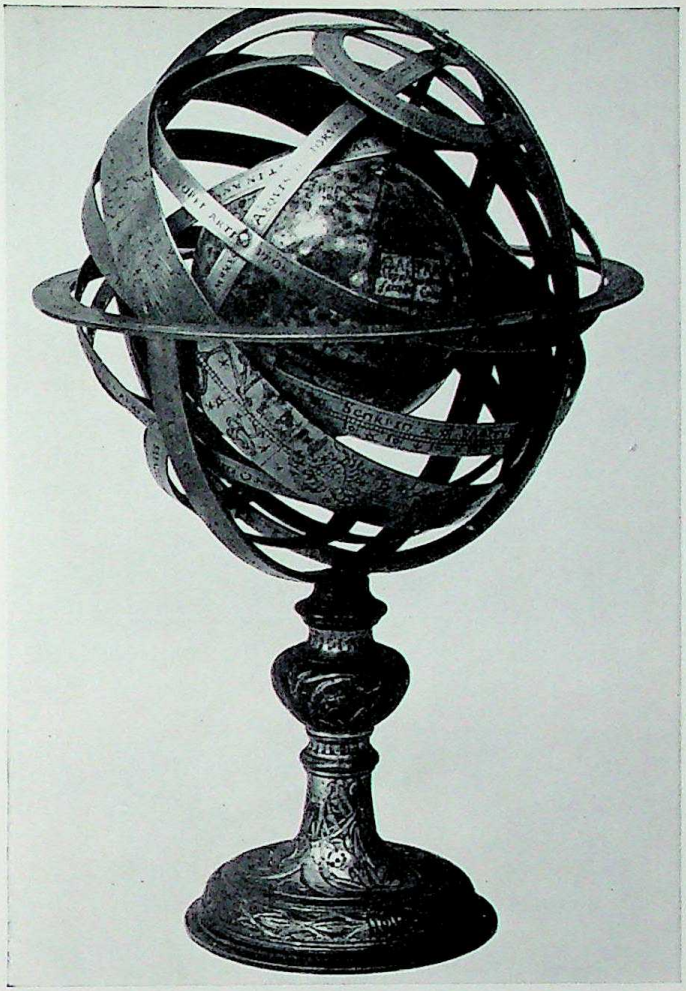
FIGURE 1 – *Celestial globe of the* Atlante Farnesiano. *A reproduction in the Warburg collection in the Zeiss Planetarium, Hamburg.*

FIGURE 2 (*right*) – *Armillary sphere by Vopel* (1542). *From an exhibit in the Science Museum, London.* (*Crown copyright, Science Museum, London.*)



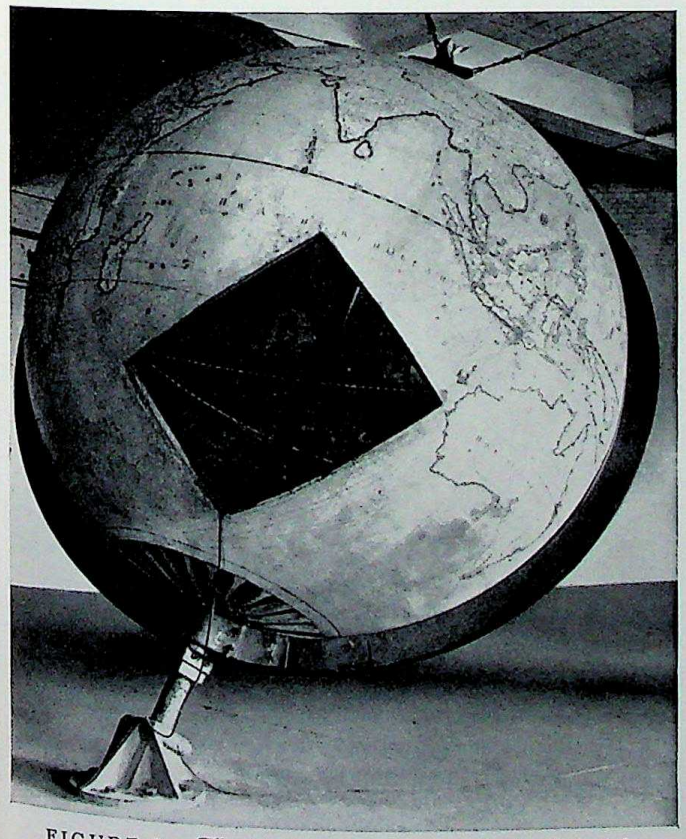


FIGURE 3 – *The Gottorp terrestrial and celestial globe.*

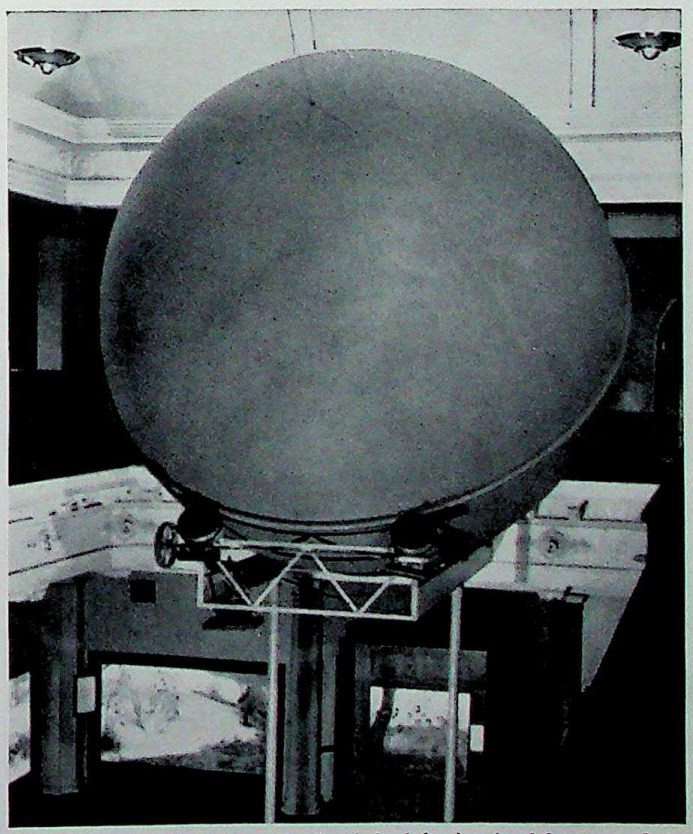


FIGURE 4 – *The Atwood celestial globe in the Museum of the Chicago Academy of Sciences.*

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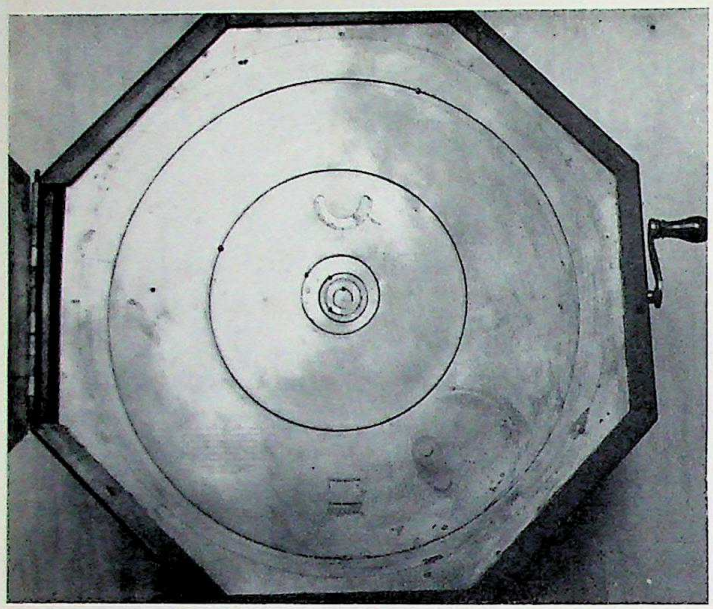


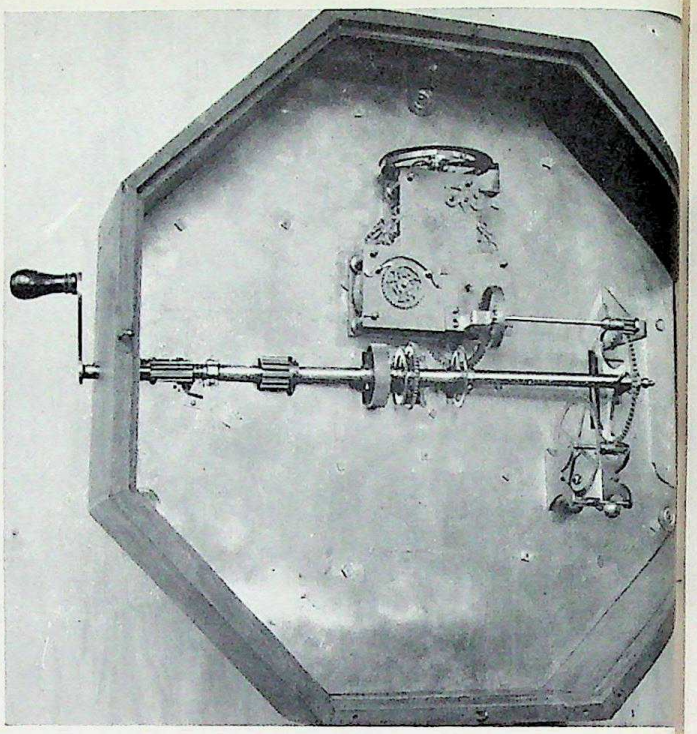
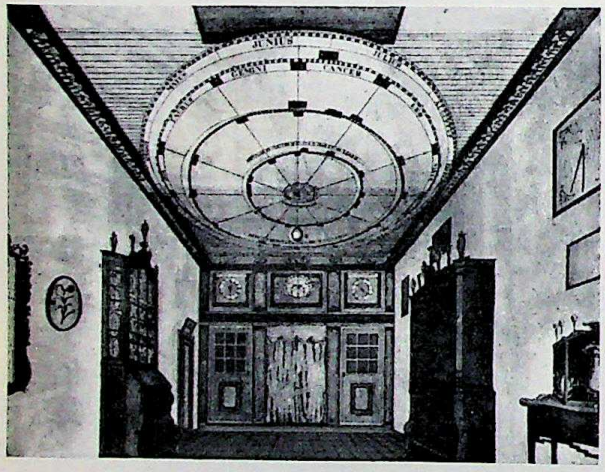


FIGURE 5 – *Huygens's planetarium, showing (left) dial and (right) the movement. (National Museum of the History of Science, Leyden.)*



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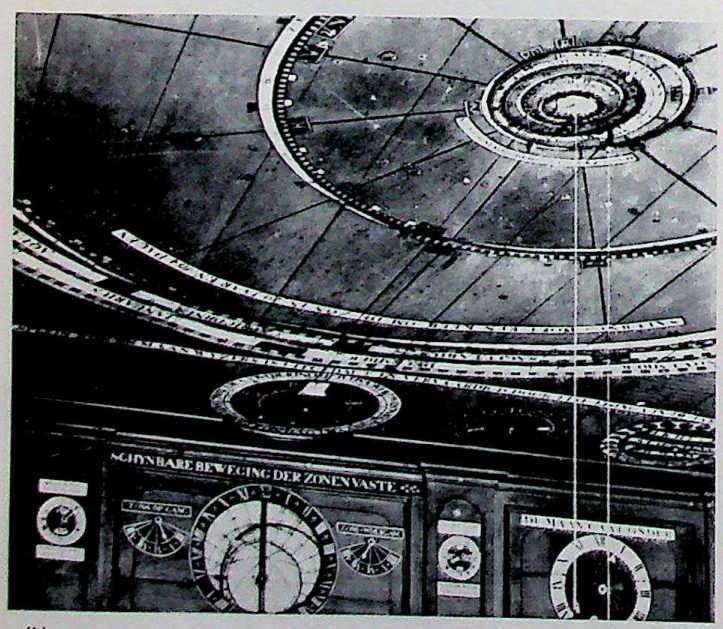

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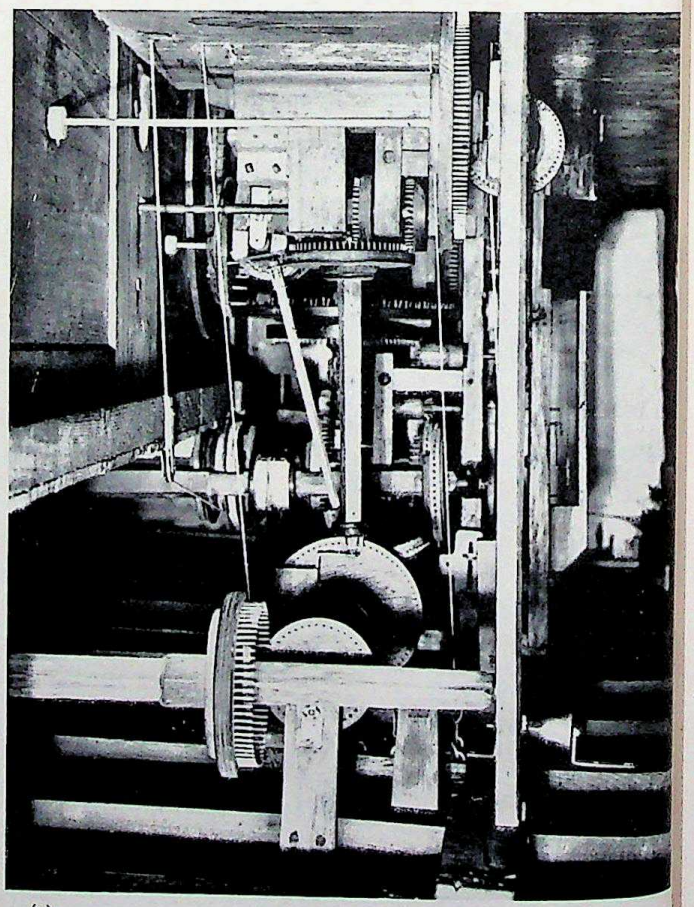

(c)

FIGURE 6 – *Planetarium of Eisinga at Franeker.* (a) *General view;* (b) *detail;* (c) *part of the mechanism.*

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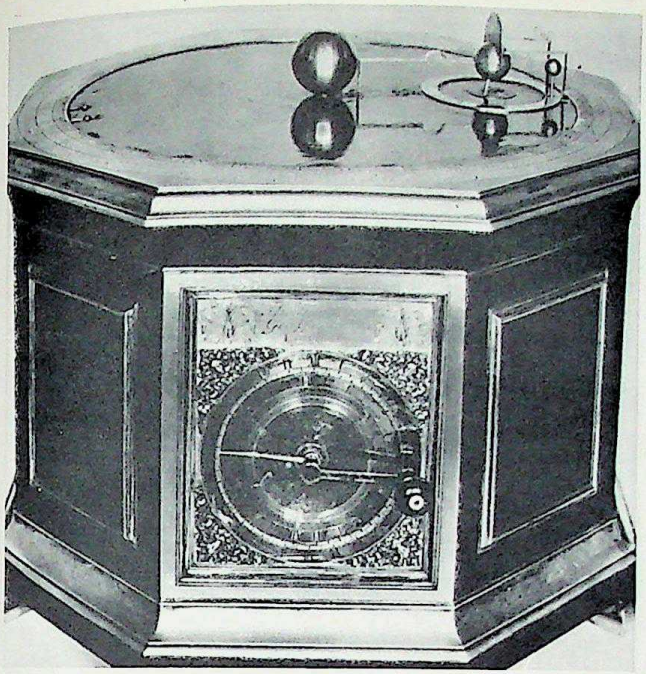

FIGURE 7 – *The Tompion and Graham orrery. (Above) general view; (below) movement with two of the stanchions removed.*

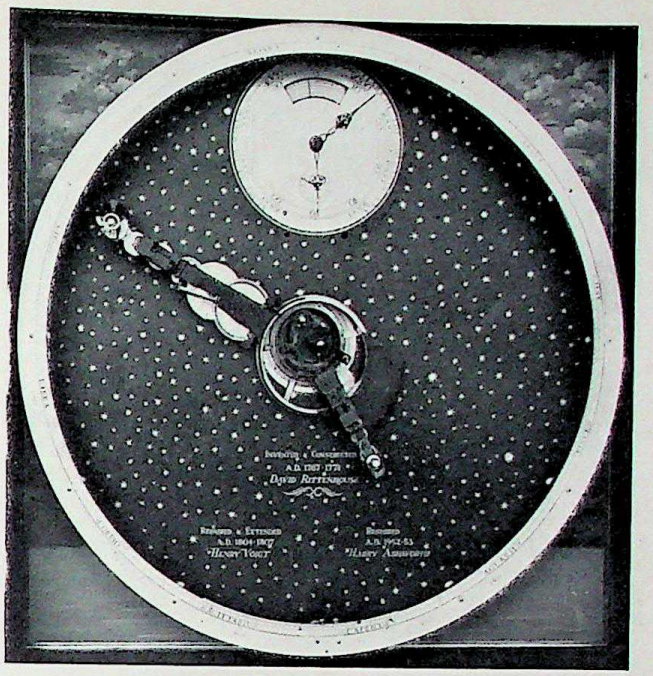

FIGURE 8 – *The central face plate of the Rittenhouse orrery in the Princeton University Library.*

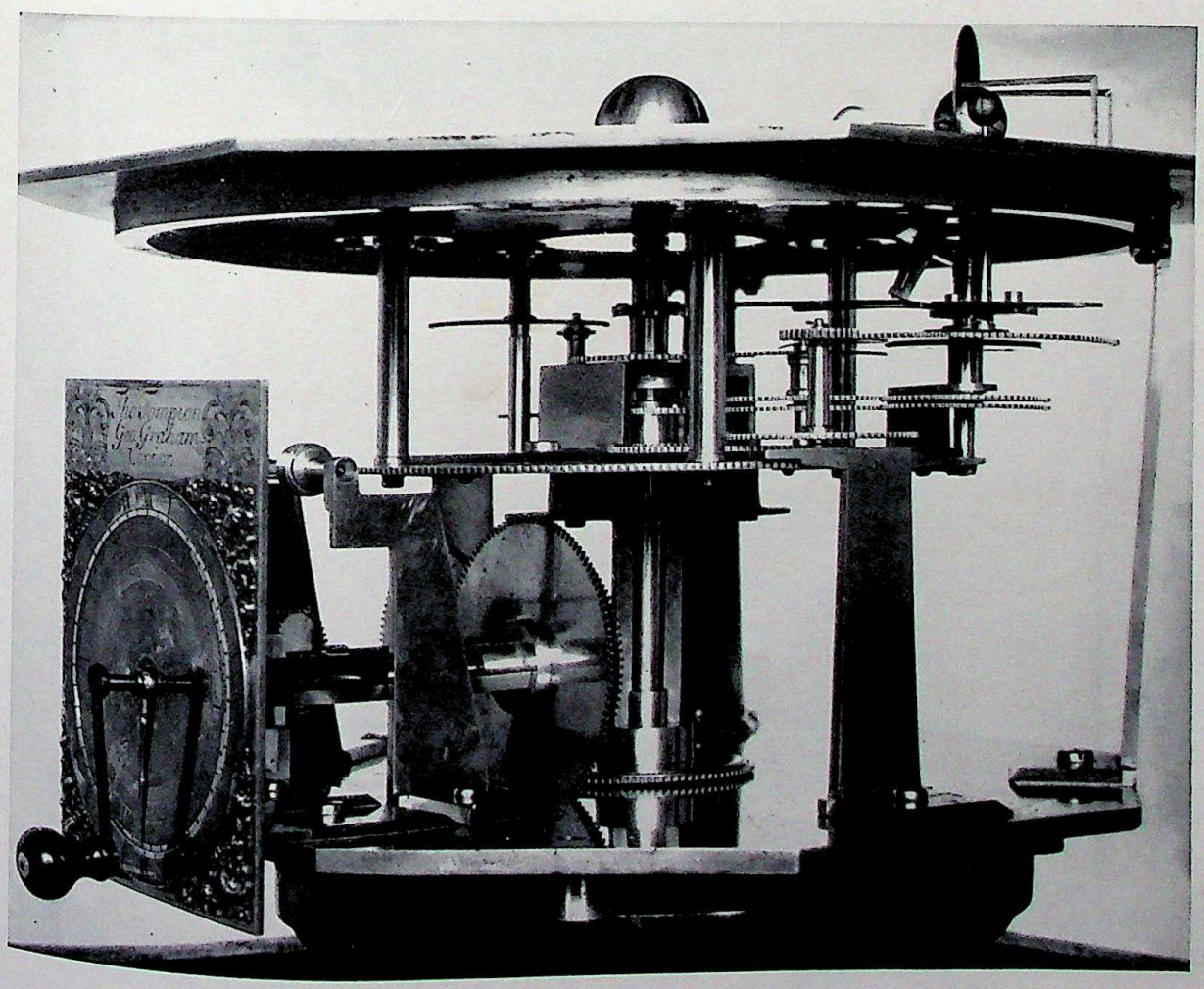

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FIGURE 9 – *Orrery by Thomas Wright.* (*Crown copyright, Science Museum, London.*)

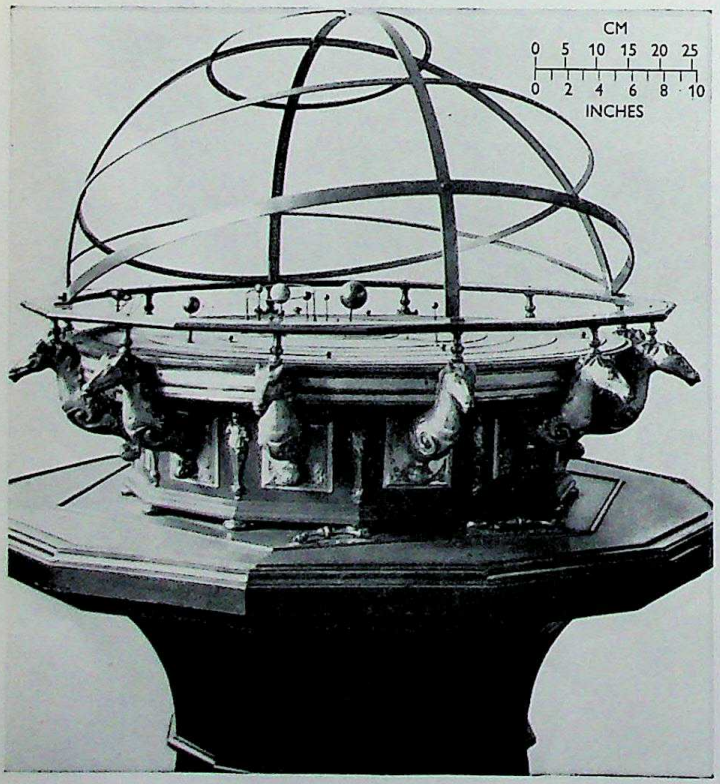

FIGURE 10 – *Large orrery by Thomas Wright.* (*Crown copyright, Science Museum, London.*)

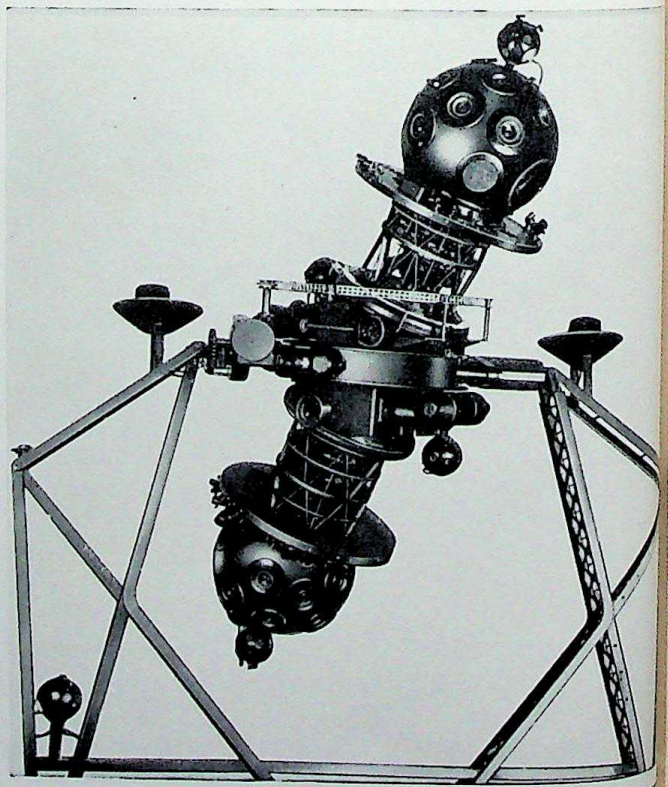

FIGURE 11 – *Latest type, or universal, Zeiss planetarium instru*

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successfully solved by the Dutch physicist, Christiaan Huygens. For this purpose he adapted the principle of continued fractions, which enabled him to show, for example, that the Earth globe and Saturn globe of a model solar system would revolve with periods in nearly the correct ratio if the Earth wheel had 7 teeth and the Saturn wheel 206 teeth. On this basis Huygens designed a small planetarium [5], operated by clockwork and gearing, which Johannes van Ceulen made in 1682 at The Hague, and which is now in the National Museum of the History of Science, Leyden (figure 5).

Van Ceulen mounted the mechanism in an octagonal box about 26 inches across and 7 inches deep in whose top copper plate he cut six circular and excentric slots. These slots correspond to the orbits of the six planets up to and including Saturn, and in each one there moves a spindle surmounted by a small model planet. Ideally the model planets should move with variable speeds in elliptical orbits, but Huygens made a clever approximation to this. Although the planets in his planetarium have uniform motions in circular orbits, these orbits are, as mentioned, excentric circles. Their centres are displaced by appropriate amounts from the Sun globe, and the model planets therefore have non-uniform motions as seen from the Sun globe. In this sense their movements represent with fair accuracy the non-uniform motions of the actual planets.

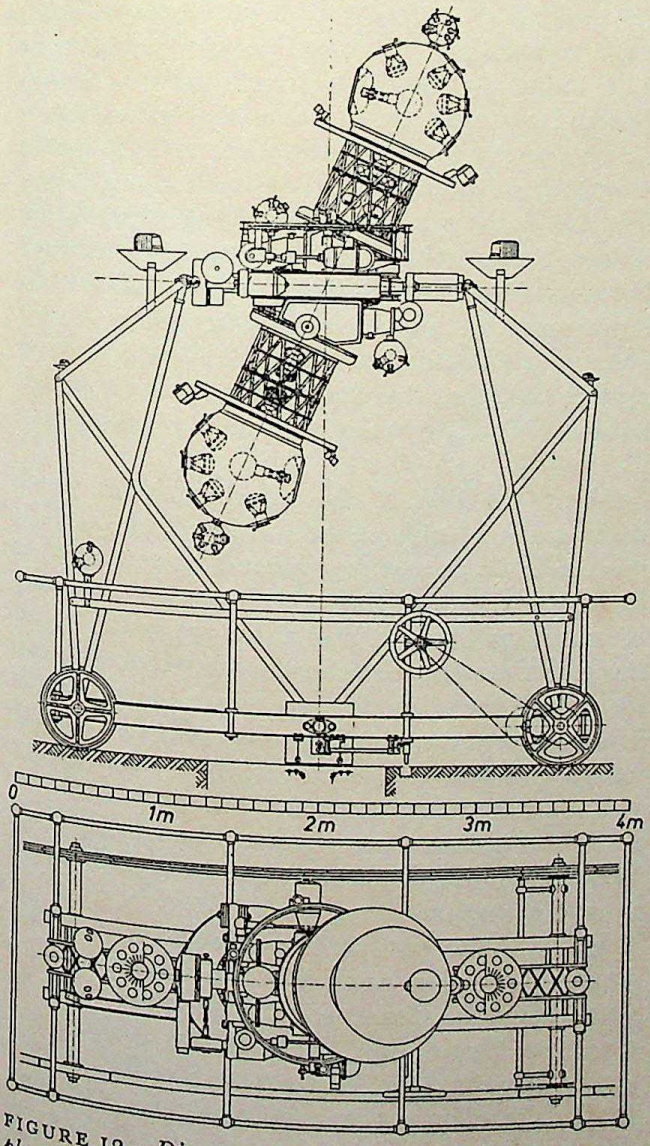

FIGURE 12 – *Diagram of the latest type, or universal, planetarium instrument.*

Huygens was by no means the only one of his time to give attention to the planetarium. In 1679 the Danish astronomer Ole Rømer sent John Flamsteed details of a machine which showed the relative movements of four of Jupiter's satellites. In England, Richard Cumberland, later Bishop of Peterborough, and Stephen Hales of Oxford made simple working models of the Earth–Moon system. George Graham, however, achieved the greatest success by making a full working model of the Earth–Moon system in which the Moon revolved about the Earth, the Earth revolved about the Sun, and both the Earth and the Moon rotated on their axes.

For many years Graham worked with the famous clockmaker Thomas Tompion and eventually became the leading scientific instrument-maker in London. His model of the Earth–Moon–Sun system appears to have been made between 1704 and 1709 and was probably the same in its mechanism and appearance as one by Tompion and Graham now exhibited in the Museum of the History of Science, Oxford [6] (figure 7). According to one account [7], Graham handed his planetarium to John Rowley, another London instrument-maker, to be packed and sent to Prince Eugene of Savoy. Rowley made several copies of the machine, presumably with Graham's consent, and sent one of them to Charles Boyle, fourth Earl of Orrery. Because of this association the device became known as an *orrery*, and the credit for its invention was at first attributed to Rowley. The instrument sent to Charles Boyle is now in the possession of the present Admiral of the Fleet the Earl of Cork and Orrery, and is on loan to the Royal United Service Institution, Whitehall, London. The mechanism is enclosed in a wooden drum or case, 30 inches in diameter and about 9 inches deep. Just above the drum, and supported by twelve gilt pillars, is the ring of the ecliptic. The Earth–Moon system is contained within a

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smaller glass-covered drum, which, with the entire top plate, rotates about the central ball of the Sun.

Rowley's orreries were highly valued both as works of art and as scientific curiosities, and several other London instrument-makers soon extended their activities in this direction. Foremost among them in this respect was Thomas Wright (see figure 9), who had his workshop under the sign of 'The Orrery and Globe' in Fleet Street. Wright introduced what later became known as the 'Grand Orrery', an instrument which showed the motions of the Earth, Moon, and the five then-known planets (figure 10). One of these instruments, made in 1733 and installed in the Royal Observatory at Richmond, is said to have cost £1500. It was transferred to King's College, Cambridge, in 1841 and is now on loan to the Science Museum, London. Wright was succeeded in this work by Benjamin Cole and his son at the same address, the Coles being followed by Edward Troughton [8]. Other orreries during this period (1730–1830) were made by the Scottish astronomer James Ferguson and by the London instrument-makers Benjamin Martin, George Adams, Heath and Wing, and W. and S. Jones.

The first American-made orrery was constructed in 1770 by David Rittenhouse, a horologist and astronomer of Norriton, Pennsylvania. Rittenhouse was the first to move the model planets in elliptical orbits and hence to represent the motions of their natural counterparts more truly than ever before. He mounted his model vertically in a handsome glass-fronted cabinet and arranged it in three sections. The central part, about four feet square, contained a working model of the solar system, the planets being actuated by turning a hand-crank. One of the side sections showed the motions of the known satellites of Jupiter and Saturn; the other contained models of the Sun, Moon, and Earth and could be used to demonstrate eclipses, the phases of the Moon, and the Sun's apparent motion along the ecliptic.

In 1771 Rittenhouse sold his orrery for £220 to the College of New Jersey, Princeton, by which time he had moved from Norriton to Philadelphia and finished a second instrument similar to the first. The second orrery was purchased by the College of Philadelphia and is now in the library of Princeton University (figure 8). Troops damaged the first machine during the War of Independence, but it was later repaired by Henry Voigt, assistant to Rittenhouse [9]. It attracted great attention when exhibited at the Chicago World Fair in 1893 and is now at Princeton University.

The largest orrery or Copernican planetarium built before the present century is that made by Eise Eisinga, a woolcomber of Franeker, near Leeuwarden, in West Friesland [10]. He began making it about 1774 and had it in full working order by 1781. The mechanism, weight-driven and regulated by a pendulum, consists largely of cogwheels in the form of oak disks and hoops fitted with metal teeth. It is concealed in the double ceiling of a living room so that the planetarium appears over the head of the observer (figure 6). On looking upwards at the main orrery the observer sees the globes of the planets in their correct relative positions and on a scale for distance of $1 : 10^{12}$. Each planet is carried round by a spindle which moves in its own circular and excentric slot cut in the lower ceiling. The globes revolve in the natural periods of the planets, that for Saturn taking nearly 29½ years to complete its path round the Sun. The Earth globe is accompanied by one for the Moon, which both revolves about the Earth and rotates on its axis once a month. Jupiter is given four satellites and Saturn has five besides its ring, but none of these has independent motion. The ecliptic is represented by a graduated band fixed outside the slot for Saturn and having the same excentricity as that given to the Earth slot. The pointer which moves against the band thereby represents the apparent motion of the Sun and shows the Sun's position in the zodiac.

Above the bed of the room are dials which indicate the Moon's phase and longitude, also the position of its apogee and ascending node. Other dials show the year, day, and hour, and the times of sunrise and sunset, and these are geared to an ingenious moving sky chart from which one can see at a glance what stars are above the horizon at Franeker at the time of observation. In 1825 the nation purchased the planetarium and Eisinga was appointed curator. After his death the house and planetarium were given to the city by King William III; the mechanism has been maintained in working order ever since.

By far the largest and most impressive Copernican planetarium is that in the Deutsches Museum, Munich. Constructed in the early 1920s by the Zeiss Foundation, Jena, it was designed by Franz Meyer, chief engineer at the Zeiss Works [11]. The elliptical iron rails which correspond to the orbits of the six planets are mounted on the ceiling of a cylindrical room about 36 feet in

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diameter and just over 9 feet high. The globes which represent the planets are driven along the rails by means of electric motors. When the room is darkened the observer sees the model planets illuminated by light from the central Sun and can watch not only their movements but also those of their satellites, and all at the rate of one year in twelve minutes. In addition, a small platform moves on the floor so that it is always directly beneath the globe of the Earth. To the platform is attached a wide-angle periscope, and when this is directed towards any one planet the observer can watch its apparent geocentric movement relative to the principal stars of the zodiac, the stars being represented by small lights inserted in the wall of the room. Similar but smaller planetaria of this type can also be seen in the Hayden Museum Planetarium, New York, and in the Morehead Planetarium at Chapel Hill, Carolina.

In addition, Oskar von Miller, Director of the Museum, had asked the Zeiss Foundation if it could produce an even more versatile instrument —one which would show the heavens and the motions of the planets from the viewpoint of one stationed on the Earth. To meet this suggestion Walther Bauersfeld of Zeiss turned from ideas which required rods, guides and cranks for moving the model planets to one which involved moving sets of optical projectors. By 1919 he had designed a large fixed hemisphere whose white inner surface acted as a receiving screen for images projected by numerous small projectors placed at the centre. By rotating these projectors, singly or in groups, images of the Sun, Moon, planets, and stars would trace out their individual paths in the planetarium sky [12].

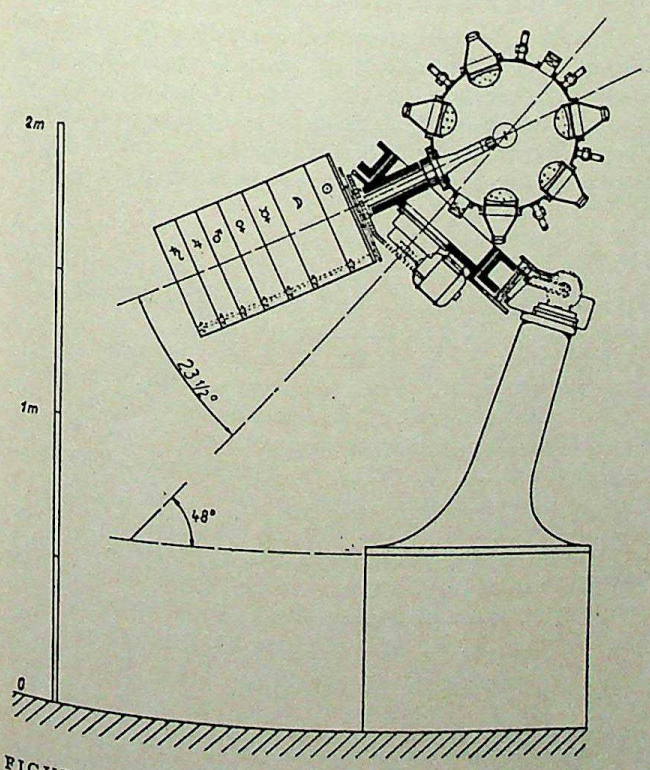

FIGURE 13 – *Diagram of the early type, or fixed-latitude, Zeiss planetarium instrument.*

After five years of intensive work the complex but compact projection instrument became a reality. When set up in a dome on the roof of the Zeiss works its performance exceeded all expectations and public interest was immediate and gratifying. In May 1925 the instrument was installed in the Deutsches Museum, Munich, where it is still in use. A second instrument, similar to the first, was built and placed in Düsseldorf in 1926. Later it was moved to Liegnitz, and then, in 1934, to its present home in the planetarium at The Hague.

The stars formed by each of the first two Zeiss instruments are projected by 31 optical systems distributed over a 20-inch globe and derive their light from a 200-watt bulb fixed at the centre (figure 13). Attached to and rotating with the star globe is a latticework cylinder which contains movable projectors for the Sun, Moon, and five naked-eye planets. These projectors are actuated through suitable gearing by an 'annual' drive which can make the Sun circle the ecliptic in periods which range from a few seconds to several minutes. Once the Sun's image is set in motion in this way, those of the Moon and planets go through their proportionate movements. Spectators see the curious geocentric motions of the planets and can watch them as they wander against the background of stars, advancing and retrogressing as if performing rhythmic arabesques.

The first two Zeiss projectors have the restriction that they show the appearance of the night sky for only one particular latitude. In 1924 W. Villiger of Zeiss effected an important modification by which the starry sky for any latitude may be shown [13]. In this design the projectors are grouped so as to form an array nearly 13 feet long and shaped like a dumb-bell (figures 11, 12). The 'balls' of the dumb-bell are two star globes which between them project about 8900 stars for the northern and southern hemispheres. The projectors for the Sun, Moon, and planets are housed in the cylindrical framework which forms the 'bar' of the dumb-bell. By suitably moving this arrangement it is possible to show the appearance of the heavens as seen from any place on the Earth and at any time past, present, or future.

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The seventeen Zeiss planetaria that contain dumb-bell type instruments have almost world-wide distribution. Rome had one in 1928 and Moscow followed suit in 1929. Ten were established in important cities in Germany and Austria between 1925 and 1928, but these have either been destroyed or are no longer in operation. In the United States of America the artificial universe was first shown to the public in May 1930 with the opening of the Adler Planetarium, Chicago. Its great success led others to appear in Philadelphia (1933), Los Angeles and New York (1935), Pittsburgh (1939), and Chapel Hill (1940). Zeiss planetaria are also in operation in Milan, Brussels, Osaka, Paris, Tokyo, and São Paulo. The latest addition to this distinguished list is The London Planetarium, which opened to the general public on 20th March 1958, and which is the first large-scale planetarium in the British Commonwealth [14]. The Zeiss instrument at London is one of a new series produced by the Zeiss works at Oberkochen, Western Germany, who have also made similar instruments for the planetaria at Tokyo, São Paulo, and Hamburg.

Not all the projection planetaria now in operation are built around Zeiss equipment. In 1935 F. D. Korkosz, technician at the Museum of Natural History, Springfield, Mass., completed a star globe projector in which numerous lenses distributed over a globe 5 feet in diameter formed images of the stars on a hemispherical ceiling [15]. Then in 1952 the technical staff of the California Academy of Sciences completed a large Zeiss-type projector which is now installed in the Alexander F. Morrison Planetarium, San Francisco [16].

By far the largest number of projection planetaria, at least in the United States of America, are products of Spitz Laboratories of Yorklyn, Delaware. Spitz instruments range in size from small table models to a large projector which incorporates several Zeiss features and possesses the characteristic dumb-bell shape. In use, however, the Spitz dumb-bell is hung by slender cables from the projection dome, a mode of support which minimizes the occultation of projected images by the supporting framework. The faintest stars are formed by sending light from concentrated zirconium arcs through 3083 pinholes distributed over the two star globes. The 54 brightest stars are produced by individual lens systems, the image of Sirius, the brightest star, being less than $1\frac{1}{4}$ inches in diameter on a 60-foot dome. A large Spitz projector was installed in 1954 in the municipal 'Planetario', Montevideo, Uruguay [17], and other projectors of the same type have just been mounted in planetaria at Flint, Michigan, and at Colorado Springs, Colorado.

So far, therefore, the projection planetarium is unrivalled not just as an educational aid but also as a cultural attraction, and the modern planetarium instrument, so remarkably complex, versatile, and accurate, will long be regarded as a masterpiece of optical engineering.

ACKNOWLEDGMENT

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REFERENCES

[1] CICERO, 'De Republica', Book 1, Ch. XIV.
[2] STEVENSON, E. L. 'Terrestrial and Celestial Globes', p. 73. Yale University Press, New Haven. 1921.
[3] SMYTH, W. H. 'A Cycle of Celestial Objects', II, 179. J. W. Parker, London. 1844.
[4] ATWOOD, W. W. *Sky*, **2**, No. 6, 12, 1938.
[5] CROMMELIN, C. A. *Antiqu. Horol.* March 1955.
[6] GABB, G. H. and TAYLOR, F. SHERWOOD. *Connoisseur*, **122**, 24, 1948.
[7] DESAGULIERS, J. T. 'A Course of Experimental Philosophy'. London. 1734.
[8] COOKE, TROUGHTON and SIMMS LTD. 'At the Sign of the Orrery', York. (No date.)
[9] GILLINGHAM, H. E. *J. Franklin Inst.*, **229**, 81, 1940.
[10] SIXMA, H. *Pop. Astr.*, **42**, 489, 1934.
[11] MEYER, F. A. *Z. Ver. dtsch. Ing.*, **69**, 1425, 1925.
[12] WERNER, H. 'From the Aratus Globe to the Zeiss Planetarium'. Translated by A. G. Degenhardt. Gustav Fischer, Stuttgart. 1957.
[13] VILLIGER, W. 'The Zeiss Planetarium'. W. and G. Foyle, London. 1926.
[14] KING, H. C. *Observatory*, **78**, 69, 1958.
[15] 'New Planetarium', *Sky*, **2**, No. 2, 15, 1937.
[16] MILLER, R. C. (Editor). 'The Story of the Alexander F. Morrison Planetarium'. (No date.)
[17] COLES, R. R. *Sky and Teles.*, **13**, 292, 1954.

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Stellar associations

V. A. AMBARTSUMYAN

Some of the major problems of astronomy concern the ages of the various stars and the processes of star formation, including the question of whether stars are still coming into being. The discovery and study of the stellar associations have provided relevant evidence, and this evidence, together with that obtained by studying other groups, is discussed here.

Astronomers have recently paid considerable attention to the study of age differences between stars. Many of the results have been obtained by the discovery and study of a newly discovered kind of stellar system, the stellar association. Moreover, it can be said that such investigations first made possible a definite assertion that the formation of stars in our stellar system—the Galaxy—is still in progress. By comparing the numbers of stellar associations in various other galaxies of different types, we can draw conclusions concerning the relative amount of star formation in them.

Stellar associations form part of the structure of a galaxy and are akin to the open clusters of stars, groups which have long been known. Some information concerning the ages of the stars and the process of star formation can be obtained from the open clusters. We shall therefore discuss how such information may be obtained.

Observation shows that our Galaxy includes groups of stars in which the star density is higher than in the general star field surrounding them. Each such group as a whole executes a motion round the centre of the Galaxy, similar to that of the Sun and other single or multiple stars. These groups are called stellar clusters. Any star which is a member of such a cluster participates in the general motion of the cluster round the centre of the Galaxy and also executes some motion about the centre of gravity of the cluster. In this respect stellar clusters are analogous to double and multiple stars.

Stellar clusters are of two types. Some clusters contain upwards of tens of thousands of stars. These are the globular clusters. Their structure exhibits a fairly exact, though not always precisely spherical, symmetry. The globular clusters are found both near the galactic plane and at great distances from it.

Other clusters do not possess such a regular form and are much less rich in stars. They contain tens or hundreds, or occasionally thousands, of stars, and are found only near the plane of the Milky Way. Such clusters are called open clusters or galactic clusters. The Pleiades and the Hyades, which are visible to the naked eye, are examples. One of the most beautiful objects to be seen through a small telescope is the double cluster in Perseus, which is at a distance of about 6000 light-years.

The globular and open clusters differ also in the composition and nature of their stellar populations. The open clusters usually contain some blue giants, that is stars having both high luminosities and high temperatures. The globular clusters do not contain blue giants but always contain red giants, stars having low temperatures and very large radii.

Calculation shows that the members of a stellar cluster are retained in it by the forces of their mutual attraction according to the inverse square law. If each cluster were isolated, the processes occurring in it would be entirely determined by these forces. In 1934, however, B. J. Bok called attention to the following point. The stars of the Galaxy in general may pass through or near a cluster with velocities considerably greater than those of the cluster members relative to its centre of gravity. They will then lose some of their energy to the cluster. Consequently the energy of the cluster will increase, and so will its dimensions. After many such passages, the cluster stars will acquire velocities sufficient for them to move apart. The cluster is thus broken up.

It was found that this means of breaking up the cluster is unimportant for globular clusters, whose density is high and whose break-up therefore requires a large amount of externally supplied energy. However, the process indicated by Bok must be very effective as regards many open clusters, whose density is low, so that the gravitational interaction between their members is slight. The break-up of open clusters by this process is calculated to occur in a time of a few thousand

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million years, which is comparable with the lifetimes of the stars.

In 1937 the present author showed that there is another break-up mechanism, which in the majority of cases is the more effective. It operates even for those open clusters in which the star density is relatively high. It arises as follows. The motion of the stars in the cluster itself sometimes results in close encounters between them, and the stars which approach each other exchange energies. In some cases one of the stars acquires so much energy that it can overcome the gravitational field and leave the cluster. By the repetition of this process the number of stars in the cluster is reduced, and the cluster gradually becomes an ordinary multiple star.

This sequence of events leads to the break-up of some clusters after a time of the order of a thousand million years, or even less. The fact, therefore, that such clusters are still observed shows that their age cannot exceed one thousand million years. These clusters, therefore, are of an age considerably less than the mean age of the stars in the Galaxy.

It is very important in this connection that the reverse process, the formation of a cluster from stars previously independent, is practically impossible. In other words, the disintegration of clusters in the Galaxy is a one-way process.

If the cluster cannot have been formed from separate stars already existing, it is evident that the process of formation of the cluster was also that by which the stars in it were born. We thus conclude that stars may be formed in groups. It is also clear that different open clusters are of different ages. This means that many clusters were formed when the Galaxy was already in existence.

At the time when these conclusions were drawn it was still not realized that they are of profound importance in the general problem of the origin of the stars. It seemed then that the results obtained referred only to stars in clusters, which form only a small part of the total number of stars in the Galaxy.

At about the same time, however, statistical investigations were being conducted on double stars, which form a very large part of the total number of stars in the Galaxy. These investigations showed that the components of each double star have a common origin. That is, double stars cannot have arisen by the combination of previously independent single stars of the general galactic population.

The deep significance of all these results became clear only much later, soon after the Second World War, when the stellar associations were discovered.

STELLAR ASSOCIATIONS

As we have seen, the open clusters have a star density exceeding that in the surrounding space. Although the star density in the open clusters is much lower than in the globular clusters, they still represent marked concentrations of stars in comparison with the galactic star field around them. The stellar associations are groups of stars in which the star density is lower than that of the background of stars nearby. This does not mean that the stellar associations are rarefactions in the Galaxy. The surrounding stars which are not members of a given association penetrate freely into the volume occupied by it, and so the total star density in that volume is higher, not lower, than in the surrounding space. When we speak of the density of the association, however, we ignore the density due to stars which do not belong to the association and consider only the group of stars which do belong to it. This density is very low, and in this sense the stellar associations are extremely rarefied groups of stars.

The contrast in the density distribution must be reduced by projection on the celestial sphere. If the space density in the region of the association is only a little above that in the surrounding region, then, since we observe only the projection on the celestial sphere, the contrast in density between the association and its surroundings will be entirely negligible. Hence it would be almost impossible to discover associations by examining the apparent distribution of the stars as a whole, whereas ordinary star clusters are revealed on star maps and photographs in this way.

The chief feature of the stellar associations is that the large majority of the stars forming any one association have similar physical characteristics. Thus the members of the associations are mainly in certain definite physical states. This fact made possible the discovery of associations in our Galaxy.

The stellar associations may be assigned to one of the following two classes: the O associations, which consist of large numbers of hot giants, that is, stars of spectral classes O and B and relatively small numbers of other objects; and the T associations, which consist of relatively cool dwarf stars, many of which exhibit irregular variations in brightness.

If we draw a map of the sky which shows only

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the blue giants (O and B type stars), the O associations appear immediately as concentrations of stars. This must occur, because the O associations represent very dense regions in the density distribution of the blue giants taken alone.

Similarly, if we insert on the map the known irregular variables of low luminosity (called RW Aurigae type variables), we find that the great majority of them are concentrated in certain regions of the sky. Thus the T associations are very marked concentrations in the density distribution of these variable stars, taken alone.

Since, however, all the blue giants and all the irregular variables of the RW Aurigae type form only a small part of the total number of stars, the associations are almost unnoticeable on maps and direct photographs showing the distribution of all the stars.

Some O associations, nevertheless, which are remote from the galactic plane and relatively near to the Earth will be noticed as groups of stars of high apparent luminosity even against the general background of stars, since in those parts of the sky there are few giant stars in the general background. An example is the dense association in Orion. It includes the bright stars in Orion's Belt and some other bright stars.

The difficulty of directly discovering O associations is due to the fact that numerous other stars of low luminosity but relatively near at hand have about the same apparent brightness as the giants in the associations. The situation is entirely different when we observe other galaxies. All the stars of any other galaxy may be supposed to be at the same distance from us. Hence the bright stars, especially the supergiants and the giants, will stand out from the remainder on account of their high apparent luminosity. The O associations, which contain hot giants, will appear as extensive groups of bright stars. Many such groups are observed, for example, in the Greater Magellanic Cloud. They occur also in the Lesser Magellanic Cloud but are not quite so obvious there, since the luminosity of the brightest stars in associations is somewhat less in the Lesser than in the Greater Magellanic Cloud. O associations are also obvious in the galaxy M33 and the irregular galaxy IC1613.

In a remote galaxy, where the stellar associations cannot be resolved into separate stars, the O associations may appear as concentrations that can be distinguished by their colour, which is bluer than that of the rest of the galaxy.

The O associations are not found in galaxies of the elliptic type, and are relatively rarely found in those of type Sa, where they are not conspicuous. They are very frequently found in late-type spirals and irregular galaxies. These facts are of great interest. The associations are closely related to the spiral structure of the galaxies; in all the spiral galaxies they lie along the arms. It is certain that this relation between the O associations and the spiral arms is of profound significance in cosmogony. The T associations cannot be observed in other galaxies, since they consist of stars of very low luminosity. However, we can obtain some idea of the existence or otherwise of T associations in various types of galaxy from the fact that in most cases they are associated with clouds of cosmic dust. Hence, for example, we may conclude that they do not occur in the elliptic galaxies, since the latter do not contain any notable dark nebulae.

SIZE AND STRUCTURE OF STELLAR ASSOCIATIONS

As has already been mentioned, the mean density of O associations is much less than that of open clusters. Their dimensions, on the other hand, exceed those of open clusters by one or one and a half orders of magnitude. The largest diameters of open clusters lie between 2 and 8 parsecs,[1] while the dimensions of O associations are usually between 30 and 200 parsecs. Still larger associations are observed in other galaxies.

An O association usually contains one or more open clusters. For example, the Orion association contains an open cluster in the neighbourhood of the Trapezium. The association known as Perseus 1 contains the double cluster h and χ Persei already mentioned, and others. The clusters which are in associations usually contain, among other stars, hot stars of type O or Bo. According to the classification devised at the Byurakan Observatory such clusters are called O clusters. The O associations contain, besides the clusters, other close groups of stars, mainly multiple systems of the type represented by the Trapezium in Orion. Such systems include three stars A, B, C such that all three distances AB, BC, and AC are of the same order of magnitude. Systems of this type are unstable, and must therefore be very young. It should be noticed that most (about 90 per cent) of the known multiple stars do not have this property. Hence the fact that Trapezium-type systems are found mainly in associations

[1] The parsec is a unit of distance used in astronomy, being the distance at which the radius of the Earth's orbit subtends an angle of one second of arc. The parsec is equal to 3·26 light-years, or about 25×10^{12} miles.

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is of great importance. Another example is the multiple star σ Orionis in the Orion association. Its principal star is of type O9, while the other four components are of type B. The Trapezium itself is also a member of the Orion association. It is at the centre of the open cluster mentioned above. Another example of a star group found in associations is afforded by the star chains such as Orion's Belt, which consists of O9 and B0 supergiants.

The close groups occurring in associations, clusters, trapezia, and chains, are usually called the nuclei of the association. Thus each O association may have one or more nuclei.

Besides nuclei and individual stars, O associations usually contain gaseous nebulae, the radiation of which is due to hot stars belonging to the association. In some cases the gaseous nebulae are so situated in the association that there can be no doubt of their genetic relation to one of the nuclei. For example, the famous nebula in Orion NGC 1976, which is in the Orion association, is closely related to the Trapezium and the surrounding cluster. Another nebula surrounds the Trapezium-type system σ Orionis. Furthermore, according to Menon, the Orion association contains very large quantities of neutral hydrogen, which emit the 21 cm wavelength radio line. In only one case, that of the association Perseus 1, has no radiating nebula been observed, and radio observations of this show no radiation of neutral hydrogen.

The most striking feature of the T associations is their close connection with the dark nebulae. The members of these associations are embedded in such nebulae. This hampers the investigation of the star distribution in T associations, since the light of many of their members is absorbed by the nebulae. Nevertheless, the data available indicate that T associations contain separate concentrations of stars, similar to the nuclei of the O associations.

As has been said, the T associations contain irregular variables of the RW Aurigae type. Some of these variables have bright-tone spectra. The prototype is the variable T Tauri. Many members of T associations were, in fact, discovered from the bright lines in their spectra, that is because they had spectra of the same type as T Tauri. However, not all RW Aurigae variables are stars of T Tauri type, although all T Tauri stars, apparently, are irregular variables of RW Aurigae type.

The question arises whether the T associations contain dwarfs of constant brightness as well as the RW Aurigae-type variables. Unfortunately this question is difficult to answer, since dwarfs of constant brightness belonging to T associations could not be distinguished from the multitude of similar dwarfs belonging to the general star population. This hampers the study of the structure of T associations. The dimensions of these associations lie between a few parsecs and 100 parsecs. In some cases they are quite dense groups, in others they are rarefied and less dense than the surrounding stars.

THE INSTABILITY OF ASSOCIATIONS

Every stellar system in the Galaxy, including clusters and associations, is subject to tidal forces due to the general gravitational field of the Galaxy. These forces tend to break up the system and to cause its members (in this case, stars) to move in independent orbits round the centre of the Galaxy. If the density of the system is high the gravitational interaction between its members is strong, and the tidal forces are unable to break up the system. It is found that the limiting density below which a system is rapidly broken up by the tidal forces is of the same order of magnitude as the mean density of the galactic star population.

Since the density of the open clusters considerably exceeds that of the galactic population, the tidal forces cannot rapidly break up a cluster. We have seen that the associations, on the other hand, have a density below this critical value, and so they must be broken up by tidal forces almost as soon as they are formed. The time necessary for this process is of the order of 10^7 years. Hence it follows that the age of the stellar associations is of the order of 10^6 years, and in some cases less still.

Since the mean age of the stars in the Galaxy is of the order of thousands of millions of years, and since the associations cannot be formed from previously existing independent stars, we must conclude that the formation of stars in the Galaxy is still in progress.

It can be shown that, if an association is broken up by tidal forces, its final disruption is preceded by the assumption of a very elongated form. Many associations of considerable size, however, are almost spherical. The association Perseus 1 is an example. The only possible explanation of this is that the stars in each such association were ejected from its central regions at the time of their formation, with speeds of the order of tens of kilometres per second. This value is derived theoretically from the sizes of the associations.

In 1952 the Dutch astronomer A. Blaauw, from a study of stellar motions in the association

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Perseus II, found that the stars are moving away from the centre of the association at an average speed of about 12 km/sec. Thus the main conclusion of the theory of stellar associations was confirmed. Later the phenomenon of expansion in the O associations Cepheus II, Lacerta, and others was detected by investigating the motions of stars in them.

The proof of this expansion was in turn a direct proof that the members of the associations are young stars, and made possible a more precise determination of their ages. The age of the stars in the association Perseus II, for example, was found to be about 1·3 million years. Ages of a few million years were obtained for other associations.

However, the existence of several nuclei in dense O associations showed that it is not possible to reduce the motion of all the stars in associations to divergence from a single centre. It is natural to suppose that the various nuclei are different centres of star formation, so that the complete picture of stellar motions in the dense associations must be less simple.

The first indications of this were detected by Artyukhina, who showed that in the association Cepheus II there are two centres from which the stars are diverging. The Orion association is more complex. According to Blaauw and Morgan, two stars of early spectral type (AE Aurigae and μ Columbae) are moving very rapidly away from a point near the great nebula in Orion. The investigations of Strand have shown that the cluster around the Trapezium is expanding at about 5 km/sec. This means that the age of this cluster cannot exceed 3×10^5 years, in good agreement with the supposition that Trapezium-type systems are very young. Thus it may be regarded as established that the Orion association contains two expanding groups. It is also certain that this association contains other groups whose motion is different from either of these. For example, there is strong evidence that the three stars of Orion's Belt have a common origin. It has not yet been possible, however, to elucidate the law of motion in this group, on account of the smallness of the relative velocities.

The presence in dense O associations of separate groups formed at different times and expanding independently is an important fact, which must be taken into account in any attempt to reconstruct the origin of the O associations.

THE ORIGIN OF O ASSOCIATIONS

If we follow backwards in time the evolution of an association, we find that each expanding group must at one time have occupied a considerably smaller volume than it does at present. The main question, however, is what the volume of the expanding group was when its stars separated from some primitive body to form isolated objects. It must, of course, be assumed that the luminosity of these objects in the early stages may have been entirely different from that which resulted when each became a star in a more or less steady state.

The fact that systems of the Trapezium type are observed in the associations—systems which are unstable, yet have dimensions of only about 0·1 parsec—indicates that the original volume may have been very small. If we go further, and postulate that the Trapezia, in the early stages of their development, were still denser groups, we reach the conclusion that the pre-stellar body from which the expanding group was formed was of high density. It must also have been very massive, having some hundreds or thousands of times the Sun's mass. Neither observation nor theory indicates that equilibrium configurations of such large masses can exist with dimensions of the order of stellar radii or a few orders of magnitude greater. The present author therefore advanced the hypothesis that the pre-stellar body was 'superdense'. The density of this 'protostar' may have been of the same order as that of an atomic nucleus. It may be that protostars in this state have very low luminosities, and so we have not yet observed them.

It should be emphasized, however, that there is as yet no logical theory of the structure of such protostars such as would explain how the matter in them is subsequently transformed into ordinary stars moving apart at considerable speeds.

A less hypothetical way in which stellar associations might be formed has been suggested by J. H. Oort. According to him, an O-type star in a very massive nebula causes the inner parts of the nebula to become hot and expand. The result is that a compression of the gas occurs in a region at the boundary between the heated inner parts and the outer parts. Owing to the gravitational instability of the resulting condensations, stars are formed at the boundary of the nebula and move away from its centre. It seems to the present author that this theory contradicts the observed fact that Trapezium-type multiple systems, that is, groups of very young stars, are found in the very centres of nebulae.

It should be noticed that the idea that stars are

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formed from gaseous nebulae is in accordance with the traditional cosmogonical theories that all celestial objects are formed from nebulae. However, our supposition that groups of stars are formed from superdense protostars necessarily leads to the conclusion that the stars and nebulae were formed simultaneously from the protostar. On this theory, the expansion of the star group and that of the nebula are related phenomena caused by the break-up of the protostar. It should be noted that the idea of the formation of expanding nebulae from dense objects (supernovae, planetary nebulae) is already familiar in astronomy. Thus our viewpoint is to some extent in accord with a tendency known to exist in Nature.

NON-STEADY STARS

As we have seen, the members of T associations are variable stars of the RW Aurigae type. These stars exhibit extremely irregular variations in brightness. It is therefore certain that they are not in a steady state. This is natural, since the members of T associations are young stars.

However, the spectra of some of these objects have interesting features which compel the conclusion that they are emitting not only thermal radiation, i.e. radiation such as we receive from ordinary stars, but also non-thermal radiation, e.g. bremsstrahlung, solar radio waves, and so on. The non-thermal radiation is due to some unknown cause which operates from time to time in the atmospheres of non-steady stars. Whatever the actual mechanism of its emission, it is now clear that it contains energy liberated from powerful sources of some kind in the outermost layers of the star. Thus, in these stars, processes of energy liberation occur not only in the central regions but also in the atmosphere.

The Mexican astronomer Haro has shown that the non-steady stars in T associations include some which 'erupt', their luminosity increasing by several times in a few minutes. In such cases the energy released in the star's atmosphere from unknown sources is emitted during a very short time, and the process of energy release is explosive. How can these phenomena be explained?

Since the non-steady stars discussed here are young objects formed from superdense pre-stellar matter, we may suppose that some of this matter, still unconverted into ordinary stellar matter, remains in them. When the remaining islands of superdense matter in the star reach the outer layers of its atmosphere they are converted into ordinary matter, very large quantities of energy being released.

Thus we reach the idea of quasi-steady condensations of superdense matter (at nuclear density) which spontaneously break up in the outer layers and release energy in discrete quantities, as opposed to the continuous evolution by thermonuclear processes, as in all stars. These releases of energy are then observed as eruptions of non-steady stars.

HERBIG-HARO OBJECTS

We have seen that the O associations include Trapezium-type multiple systems, which are very close groups and, to all appearances, very young objects. The T associations include objects which to some extent correspond to the trapezia. These are the Herbig-Haro objects. They are small nebulae of diameter some 10^4 astronomical units (an astronomical unit is the mean radius of the Earth's orbit) and each contain several star-like condensations. These condensations are arranged similarly to the stars in Trapezium-type multiple systems.

The spectra of the nebulae which contain these condensations are similar to that of the small nebula round T Tauri. However, many of the spectral features which distinguish the latter nebula are more marked in the Herbig-Haro objects. The present author therefore put forward the suggestion that in this case we have star groups which are at the very beginning of their life as T Tauri stars.

This view received strong confirmation from the work of Herbig, who found that in 1954 two new star-like condensations, not previously visible in photographs, appeared in one of the Herbig-Haro objects. Whether we are here direct witnesses of the formation of new stars, or whether this observation indicates the strange and powerful processes occurring in the very early life of a star, is difficult to say. There is no doubt, however, that the study of these processes will lead us yet closer to understanding the way in which the stars are born.

CONCLUSION

We see that the results obtained by astrophysicists in the last ten or fifteen years, and especially the data on stellar associations, have brought nearer the solution of problems pertaining to the origin of the stars.

The most important results are that the process of the formation of stars is still in progress in our

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Galaxy and other spiral galaxies, and that stars are formed in groups. It is certain also that the formation of expanding groups in the associations is related to the expansion of gaseous nebulae in them.

The stars formed in associations, however, have as a rule motions such that they do not go far from the galactic plane. The process here considered can therefore explain, at best, the origin of only that part of the stellar population which forms the 'plane sub-system'. By this we mean the galactic disk and the spiral arms.

There is, however, another sub-system, the 'spherical sub-system', or rather several such, whose members may pass far from the galactic plane. One of these spherical sub-systems includes the globular clusters. Another includes the short-period cepheids of the RR Lyrae type—variable stars whose period of variation in brightness is less than a day.

The question arises of the origin of these various objects. According to one theory (Baade, Schwarzschild, Spitzer), all the objects in spherical sub-systems are old, with ages exceeding 3×10^9 years. They were formed from objects in the plane sub-systems which acquired speeds enabling some of them to pass far from the galactic plane.

Another view (Kukarkin), which seems more likely to the present author, is that the great average age of the stars in the spherical sub-systems does not rule out the existence of young objects in them.

The hypothesis that star-group formation may have occurred among these objects also is supported by the presence of globular clusters there. Since the latter are never associated with conspicuous gaseous nebulae, it is evident that those who uphold the traditional view that stars are formed from nebulae must deny that young stars can exist among the members of the spherical sub-systems; but those who think it more probable that stars and nebulae are both formed from a third kind of object, the protostars, will see no reason against the continuing formation of stars even among the population of the spherical sub-systems.

We may hope that the coming years will bring the solution to this problem also. And then we shall be able to say whether or not the strange 'associations' occur even among the members of the spherical sub-systems.

Book reviews

UNDERSTANDING SCIENCE

Harvard Case Histories in Experimental Science, *edited by J. B. Conant. Vol. I, pp. xvi+321; vol. II, pp. vii+325–639. Harvard University Press, Cambridge, Mass.; Oxford University Press, London.* 1958. 80*s. the set.*

Dr Conant, in the course of a long and brilliant career as research chemist, professor, administrator, and diplomat, has had unrivalled opportunities of assessing the layman's lack of an appreciation of the tactics and strategy of science. He finds that even a highly educated and intelligent citizen without research experience will almost always fail to grasp scientific essentials, not because of his ignorance of scientific facts or his unfamiliarity with scientific jargon, but because of his fundamental incomprehension of what science can or cannot accomplish. Yet such a citizen, as a public servant, a lawyer, or a business executive, may find himself required to advise upon how a scientific or technical project can be organized and financed.

There is no easy way out of this difficulty, but Dr Conant feels that the study of 'case histories' in science may lead the uninformed layman to a knowledge of the methods by which science has progressed, and thus equip him with a critical but sympathetic attitude towards experimental investigation in whatever field he has to pass judgment. 'An intimate acquaintance with a relatively few historic cases should assist him in finding his way through the complexities of modern investigation as he listens to those who tell him what is being proposed.'

The cases selected, and very carefully and skilfully treated, are Boyle's experiments in pneumatics, the overthrow of the phlogiston theory, the early development of the concepts of temperature and heat, the atomic-molecular theory, plants and the atmosphere, Pasteur's study of fermentation, Pasteur and Tyndall's study of 'spontaneous generation', and the development of the concept of electric charge. Contributors other than Dr Conant himself are Leonard K. Nash, Duane Roller, and Duane H. D. Roller.

Though one may believe that, for the understanding of science, there is no fully effective substitute for laboratory discipline, these books will certainly go far towards achieving their object.

E. J. HOLMYARD

THEORETICAL ASTROPHYSICS

Theoretical Astrophysics, *edited by V. A. Ambartsumyan. Translated from the Russian by J. B. Sykes. Pp. xii+645. Pergamon Press Ltd, London.* 1958. £6 15*s. net.*

This is an able, valuable, and substantial addition to astrophysical literature. It deals predominantly with the theory required for the more immediate interpretation of the observations. Thus most of the book is concerned with stellar atmospheres and stellar spectra, first of normal stars and then of special stars (planetary nebulae, novae, bright-line stars). There is a considerable section on the outer layers of the Sun, including discussions of the electrodynamics of the Sun's atmosphere and of radio emission from the Sun. There are sections on radiative transfer in planetary atmospheres and on interstellar matter. In keeping with the tenor of the work, there is only a short

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section on the internal constitution of the stars.

The physical problems of the subject are discussed very fully but with the use of only the minimum amount of mathematical treatment; uncertainties and difficulties are clearly stated. The book can therefore serve both as a student's textbook and as a guide to research workers. Also, while the authors have tried to describe all existing work within their scope, it will make known to English readers the large amount of recent Russian work. The authors have revised the text for translation and inserted a graceful tribute to British contributions. The translator's skill is superb. W. H. McCREA

INORGANIC REACTION MECHANISMS

Mechanisms of Inorganic Reactions, *by F. Basolo and R. G. Pearson. Pp. xi+426. John Wiley & Sons Inc., New York; Chapman and Hall Ltd, London.* 1958. 94*s. net.*

During recent years a number of excellent books have appeared on the subject of co-ordination compounds, and it might be questioned whether there is the need for another at the present time. This new volume, however, can be sure of a good reception, for it deals with an aspect of co-ordination chemistry which is receiving increasing attention. It is devoted to a discussion of the mechanisms of the reactions of complex compounds. After a helpful introduction the author gives a clear account of the theory of the co-ordinate bond, substitution reactions of octahedral complexes, substitution reactions of square complexes, the stereochemistry of substitution reactions of octahedral complexes, oxidation-reduction reactions, and catalytic effects of co-ordination compounds. He points out that there are three theories which at present are used to explain the structure, stabilities, and general properties of co-ordination compounds. They are the valence bond theory, the molecular orbital theory, and the electrostatic theory, including crystal field corrections. The author concedes that all three can account in a qualitative way for the main features of complexes. However, when it comes to the quantitative calculations he unhesitatingly places the 'electrostatic-plus-crystal-field' theory well in the lead. The authors deserve the thanks of all chemists for making available in such an attractive form an account of important advances in the field of metal complexes. W. WARDLAW

STEROID CHEMISTRY

Chemistry of the Steroids, *by C. W. Shoppee. Pp. vii+314. Butterworths Scientific Publications Ltd, London.* 1958. 50*s. net.*

As a complex problem of structural analysis, and later of synthesis and biosynthesis, the steroids forced the development of new analytic and synthetic methods. As non-aromatic but fairly rigid frameworks of carbon atoms they promoted knowledge of aliphatic substitution and elimination, rotation differences, rotatory dispersion, and absorption spectra. Their importance in animal physiology stimulated invention of new chemical methods to make possible the production of rare but potent steroids from plentiful raw materials.

In Professor Shoppee's book these wider horizons can be glimpsed through the forest of a closely packed text. By using description with a minimum of explanation he largely succeeds in his aim of presenting concisely the state of knowledge of steroid chemistry in 1955–56; an almost total neglect of steroid alkaloids is the principal omission. The work is well arranged, clearly worded, and usually accurate. Formulae are well drawn and the printing is excellent. The short section on biogenesis is, however, spoilt by incorrect formulae for squalene and lanosterol, and double bonds in the side-chains of ergosterol, stigmasterol, etc. are wrongly shown as *cis*.

By the specialist this book will be valued as a classified collection of abstracts. For those who seek to understand the significance of the bare facts, it will make difficult reading.

J. W. CORNFORTH

HUMAN ORIGINS

Traité de Paléontologie. *Vol. VII,* Primates: paléontologie humaine, *by Jean Piveteau. Pp.* 675. *Masson et Cie, Paris.* 1958. *Paper covers, fcs* 12 000 *net; bound, fcs* 12 800 *net.*

The seventh and last volume of this comprehensive French treatise on palaeontology is concerned with the fossil record of the Primates with special reference to the origin of man. Since the author is the distinguished Sorbonne palaeontologist, Dr Piveteau, it goes without saying that it is a thoroughly competent and authoritative work. But it has the additional value that it applies well established palaeontological principles to a particular field of evolution which all too often is apt to be expounded by writers who have had little or no experience in the study and interpretation of fossil material. About one third of the book deals with the lower, non-hominid, Primates; we could have wished that this part had been considerably expanded, in view of the fact that the records of so many important specimens of the early Primates remain scattered in so many different journals, not all of which are readily accessible. The remainder of the book covers what is often broadly called 'human palaeontology.' The author divides the course of hominid evolution into two phases; the first (by far the longest) traces the gradual evolutionary development of the prehuman representatives of the Hominidae, and the second marks the emergence of true 'man'—that is to say, of beings which have the attributes (such as a voluminous brain and the ability to fabricate tools) with which the colloquial terms 'man' and 'human' are ordinarily associated. Of the early fossils which he definitely includes in the Hominidae, perhaps the most interesting are the small-brained creatures whose remains have been found in such abundance in South Africa, the Australopithecinae. The earliest representatives of 'humanity,' in the sense in which Piveteau uses this term, are those of *Pithecanthropus* of Early or Middle Pleistocene date, and from this ancient type to *Homo sapiens* the fossil record provides a fairly closely graded sequence. Without doubt, this book is essential as a standard work of reference for all students of Primate palaeontology. W. E. LE GROS CLARK

DARWINISM TODAY

A Century of Darwin, *edited by S. A. Barnett. Pp. xvi+376. William Heinemann Ltd, London.* 1958. 30*s. net.*

These fifteen essays do not, in general, attempt to trace the course of biological thought in the period since Darwin worked. Most of them set out to explain the present position of some problem, major or minor, which engaged him and still interests us today. The result is a more striking tribute to Darwin than could have been given by any piece of pious hagiography, for his thought appears, over and over again, to be wholly relevant to contemporary studies.

Dr Barnett's distinguished contributors have served him well. All the

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essays are clearly written and will give pleasure to professional biologist, student, and serious naturalist alike. I should like to mention especially those by T. Dobzhansky on the species problem, C. M. Yonge on coral reefs, and J. Heslop-Harrison on Darwin as a botanist, as having pleased me most. D. Michie's proclamation of the dawn of a third stage in genetics is, I think, usefully provocative, though R. A. Crowson's iconoclastic attack in dealing with problems of classification seems, to a non-specialist, to misfire. J. Maynard Smith on sexual selection, and W. E. Le Gros Clark on the descent of man are both admirable. There are essays on Darwinism and sociology and on the possible implications of evolution for ethics. D. R. NEWTH

MUCOPOLYSACCHARIDES

Ciba Foundation Symposium on the Chemistry and Biology of Mucopolysaccharides, *edited by G. E. W. Wolstenholme and Maeve O'Connor. Pp. xii+323. J. and A. Churchill Ltd, London.* 1958. 54*s. net.*

Mucopolysaccharides and mucoproteins are substances containing complex macromolecular carbohydrates and amino acids. Their detailed chemistry is as yet ill defined, though their biological importance is profound since they form important constituents of living cells. The book describes a timely discussion by a relatively small group of experts from many countries who were brought together by the Ciba Foundation under the able chairmanship of W. T. J. Morgan.

The general organic chemical techniques applied to problems of structure in the group is reviewed by M. Stacey, the physico-chemical approach is described by reference to hyaluronic acids by A. G. Ogston, while the novel immunochemical method of determining structure is ably outlined by E. A. Kabat. The latter method, involving the specific inhibition of complex immunochemical reactions by means of disaccharides and oligo-saccharides of known structure is already proving particularly valuable in throwing light on the molecular architecture of blood group factors and of the pneumococcus and other bacterial specific polysaccharides.

A number of discussions by Jeanloz, Partridge, Dische, and colleagues on the sulphated amino sugar-containing mucopolysaccharides are described, special attention being paid to the chondroitin sulphate complex in cartilage and to connective tissue constituents. There is a provocative account (Meier) of the pharmacological effects of polysaccharides and an important one (Westphal) on the components of Gram-negative bacteria. Other interesting subjects discussed are the nitrogen-containing saccharides in human milk (Gyorgy), blood group specific substances (Morgan)and the mucopolysaccharides of epithelial mucus (Odin), plasma (Winzler) and urine (Maclagan, Anderson). Perhaps the most important chapters are those describing the sialic (neuraminic) group of compounds and their relationship to influenza virus. Sialic acid was discovered over 20 years ago by Blix in submaxillary mucus and although very labile it was later crystallized by him. Klenk obtained the same substance from the degradation of gangliosides and it is cropping up in free or bound form in many places where tissue material is being examined in health and disease. The experts, Blix, Klenk, Gottschalk, Svennerholm, and others, bring the subject up to date.

The discussions are faithfully described in all sections. They are exciting and stimulating and this book, which is well up to the standard of previous Ciba Foundation books, will need to be read by all biochemists. M. STACEY

PLANT GROWTH

Control of the Plant Environment, *edited by J. P. Hudson. Pp. xvi+240. Butterworths Scientific Publications Ltd, London; Academic Press Inc., New York.* 1957. 42*s. net.*

The symposia held at the School of Agriculture in the University of Nottingham have rapidly become established as a valuable meeting place of biological and agricultural sciences. In this book Professor Hudson has promptly and successfully recorded the proceedings of the symposium which was held at Sutton Bonnington in 1957.

A central theme running through the papers and discussions was the study of the growth and development of plants under controlled environmental conditions. Plant physiologists and all those concerned with the basic problems of plant culture will find much to interest them: it is primarily a book for the specialist.

In the first two parts of the book ten main contributions are reported. Some of them are general reviews, of rather variable quality, of plant growth and development, while others deal more specifically with the influence of environmental factors, such as temperature, light intensity, wind, and soil moisture. More attention is given to climatic rather than edaphic conditions. The later parts of the book deal with installations and equipment which have been developed for controlling environmental conditions for experimental work on plant growth. A great range of equipment is covered, varying from phytotrons to simple growth chambers and cabinets. Although many of the accounts are very brief, they will be of particular interest to experimentalists in a field in which rapid progress is now being made. E. W. YEMM

NINETEENTH-CENTURY CHEMICAL INDUSTRY

The Chemical Industry during the Nineteenth Century, *by L. F. Haber. Pp. x+292. Oxford University Press, London.* 1957. 45*s. net.*

This attractive, original, and objective work, well documented and carrying a useful bibliography, is described as 'a study of the economic aspects of applied chemistry in Europe and North America'. But besides this it discusses the effect of chemical education—sometimes the apparent insufficiency of it—on the growth of the chemical industry, together with labour questions and sociological factors. It thus breaks new ground in a number of ways and is a valuable contribution that will be welcomed by chemists generally, especially perhaps for the light it sheds upon British and Continental interrelations. Despite the wide title, Dr Haber deals mainly with the acid, alkali, bleaching powder, and dyestuffs branches of the chemical industry, and the picture drawn, effective as it is, is not complete. It seems a pity to maintain that chemistry in the nineteenth century had at last ceased to be the 'handmaiden of medicine and metallurgy,' only to leave out both these important aspects and to present it as the handmaiden of the textile industries. It must be admitted, nevertheless, that the manufactures chosen were the most important until well into the twentieth century.

Though the author has made every effort to avoid bias, there are several places where the facts do not seem to be presented quite correctly. Black did welcome Lavoisier's views (page 31). The Institute of Chemistry, founded in 1877, was scarcely a specialist body

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(page 78) but a professional and qualifying organization—even more strictly so than the *Verein deutscher Chemiker*. It contained a strong contingent of analytical and consulting chemists, but Professor Edward Frankland, its first president, was hardly a typical British consultant (page 191); Cross and Bevan, who patented the viscose process, were perhaps more representative. Though coal-tar figures prominently as the basic raw material of dyestuffs, the increased output of benzole during the 1880s does not seem adequately explained, nor could reference be found to W. Young's patent of 1875, for the recovery of benzole from gas by oil washing, though one of Brunck's is mentioned, to which the date 1887 is given (page 86).

Despite occasioning such misgivings, however, it remains true that this is such an interesting and instructive work, and so packed with information, that it should be made available to every student of chemistry. More mature chemists will, or should, read it as a matter of course. Economists and sociologists should not overlook it.

F. W. GIBBS

HISTORY OF MATHEMATICS

A History of Mathematics, *by J. F. Scott. Pp. x+266. Taylor and Francis Ltd, London.* 1958. 63*s. net.*

This is a brief and stimulating account of the development of mathematics from the Rhind papyrus to the *Disquisitiones arithmeticae* of Gauss. Its especial value is the careful reproduction of the exact words and symbols employed by the great masters in some of their most characteristic work, and a generous appreciation of the difficulties under which they laboured. Strict chronological order is rightly subordinated to the more natural and logical scheme of following the development of ideas. The book is illustrated by five magnificent photographs of certain classical mathematical writings and provides brief biographies of the more important practitioners of this art.

G. TEMPLE

GALILEO

The Crime of Galileo, *by Giorgio de Santillana. Pp. xvi+339. William Heinemann Ltd, London.* 1958. 30*s. net.*

In 1613 Galileo wrote to Father Benedetto Castelli a letter defending against clerical criticism the Copernican hypothesis of a moving earth, including citation of the Holy Scriptures. This letter caused some commotion, especially among the less erudite and less exalted of the Church, but it was evident that the Church was not anxious to proceed vigorously against the writer if he, on his part, did not press for a ruling. Galileo, however, like certain other great men, was sardonically brilliant and powerfully controversial, rather than tactful, little able to suffer gladly fools even in high places, with the result, then as now, inevitable. How he ultimately provoked a decision which it was in his interest to avoid is, in outline, a familiar story.

In the book before us the learned author enters in great detail into the complicated chain of events, the personalities and the intrigues that led up to the trial before the Inquisition in 1633 and describes the trial itself and its aftermath. In the course of this he gives careful studies of various figures concerned, including especially Cardinal Bellarmine and Pope Urban VIII. The work evinces a close acquaintance with the historical background and the general Italian scene of the time. It sometimes happens that the account of tedious intrigue becomes itself a little tedious, but this is inevitable.

The mixture of classical Italy and modern America exemplified by the translation 'But what a pity that Mr Galileo has gotten involved in these entertainment tricks' is probably intentional, for one object of the author is to show how similar the modern United States and Galileo's Italy were in the treatment of science by the State Services and the Church respectively. In fact, he considers Oppenheimer to be in some ways a modern Galileo.

It is to be regretted that in a work of scholarship of this nature so little trouble has been taken with the references. Passages from contemporary works are introduced without any indication of origin, and books in Italian and Latin are quoted by English titles without even an indication as to what was the original language; the *Sidereus Nuncius* is cited indifferently as the 'Messenger from the Stars', the 'Starry Messenger', and the 'Sidereal Messenger'. It is strange, too, that there should be no bibliography whatever and that in the index a name like Copernicus should be followed by some forty page numbers without any indication as to what is concerned. Altogether, the serious scholar is not much helped should he wish to pursue any particular question.

E. N. DA C. ANDRADE

THE HISTORY OF MECHANICS

A History of Mechanics, *by René Dugas, translated from the French by J. R. Maddox. Pp. 671. Routledge and Kegan Paul Ltd, London.* 1957. 100*s. net.*

The task that the author has undertaken is indeed a formidable one, that of producing a history of mechanics, in all its aspects, covering the subject from the speculations of Aristotle to the achievements of de Broglie and Dirac, considering with like care the work of Jerome Cardan and of Arthur Compton, of Jean Buridan and of Niels Bohr. The scope may, perhaps, be best indicated by citing the titles of the five parts of which the work consists: 'The Origins', taking matters up to the times of Tartaglia and of Kepler's laws; 'The Formation of Classical Mechanics', including Stevinus, Huygens, and Newton; 'The Development of the Principles of Classical Mechanics in the XVIIIth Century', dealing with discovery from Jean Bernouilli to Lagrange; 'The Evolution of Classical Mechanics after Lagrange', considering developments from Laplace to Helmholtz, with Henri Poincaré's penetrating criticisms; and 'The Principles of the Modern Physical Theories of Mechanics', covering matters from the coming of relativity to the recent development of quantum mechanics by Heisenberg and Schrödinger.

René Dugas possesses the width of mind and sympathy, the depth of scholarship, and the precise knowledge necessary for such an undertaking. His book has been widely welcomed in its original French, and its English form is sure of an honoured and much visited place on the shelves of those students of scientific history to whom this language is more familiar. It is a pity that the translator has preserved many names of persons and places in French forms not used in English and in other matters has retained French conventions which, no doubt, are as well justified as ours but are unfamiliar.

Criticisms can, of course, be made in such minor matters as the neglect of Newton's foundation of the theory of wave motion, but it would be ungracious to quibble about small points when the general standard is so high and the task so demanding. Just tribute is paid throughout the book to the work of Duhem and it is to be regretted the space prohibits the reproduction here of his striking prophecy, made in 1903, of the coming scope and importance of the quantum theory. Those interested will find it on page 457.

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Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

An Introduction to Statistical Mechanics, *by J. S. R. Chisholm and A. H. de Borde. Pp. ix+160. Pergamon Press, London.* 1958. 35*s.* net.

The authors of this book use an adaptation of the Darwin-Fowler method to introduce the student without a full knowledge of the complex integral calculus to equilibrium statistical mechanics. They pay special attention to the Third Law of Thermodynamics and endeavour throughout to maintain a balance between theory and application.

Advances in Genetics, *Vol. IX, edited by M. Demerec. Pp. viii+294. Academic Press, Inc., New York; Academic Books Ltd, London,* 1958. $8.80 *net.*

This book contains six medium-length reviews of the following subjects: the population genetics of *Drosophila robusta* by H. L. Carson, the genetics of Basidiomycetes by H. P. Papazian, genetic analysis based on mitotic recombination by G. Pontecorvo and E. Käffer, an 8-chromosome map of *Aspergillus nidulans* by E. Käffer, the inviability, weakness, and sterility of interspecific hybrids by G. L. Stebbins, and the mechanism of sex determination in dioecious flowering plants by M. Westergaard. The papers are intended for research workers in these and related fields, and include lists of references.

Ion Exchange Resins (*second edition*), *by R. Kunin. Pp. xiii+466. John Wiley and Sons Inc., New York; Chapman and Hall Ltd, London.* 1958. 88*s. net.*

The increase in the utilization of ion exchange resins necessitated extensive revision of the first edition of this book, published eight years ago. The sections on permselective membranes, hydrometallurgy, sugar refining, and specific exchange resins have been enlarged to separate chapters, and new material on liquid ion exchangers, catalysis, stability, and the uses of ion exchange resins has also been added. This book is intended, as was the previous edition, to provide an overall survey of the field for those who are working in only a part of it.

Actions chimiques et biologiques des radiations. *Part III. Edited by M. Haïssinsky. Pp.* 222. *Masson et Cie, Paris.* 1958. *Paper covers, fcs.* 4000; *bound, fcs.* 4800 *net.*

This book is divided into three parts. The first, by M. Burton, deals with radiolysis of organic liquids. The second part, by A. Chapiro and M. Magat, with polymerizations brought about by radiation, and the third, by A. Charlesby, with the effect of high-energy radiation on polymers. The book is directed at the non-specialist as well as the radiochemist and radiobiologist.

The Effects of Atomic Radiation on Oceanography and Fisheries. *Pp. ix+137. Published by the National Academy of Sciences, National Research Council, Washington, D.C.* 1957. $2 *net.*

This is one of a series of studies of the biological effects of atomic radiation that was started in 1955; first reports were issued as the Biological Effects of Atomic Radiation—Summary Reports, and this is an account of the continuation of the work of one of the committees. The thirteen chapters cover in detail the various aspects of the use of the ocean as a receptacle for artificially radioactive materials as well as the use of tracer techniques, used both for the measurement of physical and chemical processes in the sea and atmosphere, and for large-scale biological experiments. There are lists of references appended to the chapters.

Extra Pharmacopoeia, *Vol. I. 24th Edition. Pp. xxx+1695. The Pharmaceutical Press, London.* 1958. 65*s. net.*

This book has been completely revised since the last edition. One alteration is that of following the lead of the British Pharmacopoeia and the British Pharmacopoeia Codex in using English instead of Latin for the main titles of drugs. The contents include a list of changes in the British Pharmacopoeia, a list of drugs, their doses and uses, and special sections on antibiotics, immunological products, and radioactive isotopes. There is a therapeutic index as well as a special index.

Aliphatic Fluorine Compounds, *by A. M. Lovelace, W. Postelnek, and D. A. Rausch. Pp. x+370. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd, London.* 1958. 100*s. net.*

The preparation and properties of all reported non-aromatic organic fluorine compounds are covered by this book. It does not give the practical details for the preparations mentioned, but provides the references; it includes 60 tables giving the physical properties of some 4500 organic fluorine compounds.

La chromatographie, *by L. Savidan. Pp. vii+109. Dunod, Paris,* 1958. *Fcs.* 680 *net.*

The theory of chromatography is dealt with in the beginning of this small book, which goes on to describe the methods, apparatus, and applications of this new technique. It is not intended to replace the standard works of reference, but is designed for chemistry students and those chemists, biologists, and other scientists who want a clear and concise introduction to chromatography.

Atomic Energy and Agriculture, *by C. L. Comar. Pp. x+450. American Association for the Advancement of Science, Washington, D.C.; Bailey Bros. and Swinfen Ltd, London.* 1957. 86*s. net.*

This is the account of a symposium presented at Atlanta in December 1955. Twenty-two papers are published, and the subjects reviewed include the uses of radioisotopes in agricultural research, radiation processing of foods, and the solubility and plant utilization of micronutrients. The papers are accompanied by extensive bibliographies.

Précis de pétrographie, *by J. Jung. Pp.* 314. *Masson et Cie., Paris.* 1958. *Paper covers, fcs.* 3600; *bound, fcs.* 4600 *net.*

This is an introductory text book for students on the use of the polarizing microscope in petrography. It aims at showing how this instrument can give information on the mineralogical constitution of rocks, and on their history and inter-relationships. There are a large number of illustrations in line and half-tone and an extensive index.

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Received his A.B. degree in chemistry from the University of California at Los Angeles in 1934 and his Ph.D. in chemistry from the University of California, Berkeley, in 1937. He is co-discoverer of nine transuranium elements, including plutonium, and of the fissionable isotopes Pu^{239} and U^{233}. He is the originator of the actinide concept for the placing of the heaviest elements in the periodic table of the elements. He, together with E. M. McMillan, was awarded the Nobel Prize in Chemistry for 1951 in recognition of his work with the transuranium elements. On leave of absence from the University of California to the Metallurgical Laboratory of the University of Chicago from 1942 to 1946, he was primarily responsible for the laboratory development of the chemical procedure which was used for the separation of plutonium at Clinton, Tennessee, and Hanford, Washington, during the war. He served as a member of the General Advisory Committee to the Atomic Energy Commission from 1946 to 1950. He became Professor of Chemistry in the Department of Chemistry in 1945 and Associate Director of the Radiation Laboratory at the University of California at Berkeley in 1954. From 1945 to 1958 he served as Director of Nuclear Chemical Research at the Radiation Laboratory. He is at present Chancellor of the University of California at Berkeley.

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Was born in London in December 1887 and was educated at St Dunstan's College, the Universities of London, Manchester, and Heidelberg, and the Cavendish Laboratory, Cambridge. He served as an artillery officer in France in the war of 1914–18, and afterwards was for some years professor at the Artillery College (later the Royal Military College of Science). In 1928 he was appointed Quain professor of physics in the University of London. At University College he established a flourishing school of physics, known for fundamental work on the mechanical properties of the solid and liquid state. In January 1950 he was appointed Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences, Institut de France.* He is known for the clarity of his exposition of science, both in writing and by lectures.

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Was born in 1922 and was educated at King George V School, Southport, and Gonville and Caius College, Cambridge. From 1943 to 1946 he worked in the Radar Research and Development Establishment of the Ministry of Supply. He then joined Professor P. M. S. Blackett's staff at Manchester University, where he was assistant lecturer, and then lecturer, in physics. He was there interested by Professor Blackett in the problem of the Earth's magnetic field, on which he has since worked. From 1948 to 1955 he was a Fellow of Gonville and Caius College, Cambridge, and in 1949 Assistant Director of Research in the Department of Geodesy and Geophysics, Cambridge University. In the summers of 1952 and 1953 he was a research geophysicist at the Institute of Geophysics of the University of California, Los Angeles. He is now Professor of Physics and Director of the Department of Physics in the University of Durham, King's College, Newcastle.

H. C. KING,
M.Sc., Ph.D.,

Was born in London in 1915 and was educated at Sir William Borlase School, Marlow, and the University of London, where he took the degrees of M.Sc. and Ph.D. in the history and philosophy of science. He was for seven years Senior Lecturer in ophthalmic optics at the Northampton College of Advanced Technology, London, and is now Lecturer-in-Charge at The London Planetarium. He has published extensively on optics, planetaria, and the history of science.

V. A. AMBARTSUMYAN

Was born in 1908. He is President of the Armenian Academy of Sciences and a member of the Academy of Sciences of the U.S.S.R. In 1945 he became director of the Abastumanskaya Observatory near Erivan in Armenia, and in 1946 and 1950 respectively he received Stalin prizes for his work on the absorption of light in cloudy atmospheres and on stellar associations. In 1948 he became a vice-president of the International Astronomical Union. His many published works deal with the properties of nebulae, the dynamics of stellar systems, and the structure of stars.

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Svante Arrhenius (1859–1927)

The legend dies hard that science is a purely objective and logical study in which the personalities of those concerned play no part. Research workers, however, are aware—often painfully so—of the difficulty of getting new ideas accepted, and the history of science offers innumerable examples of the way in which important theories have been established only in the face of bitter and uninformed opposition. Of this, few examples are more striking than that of Svante Arrhenius, the centenary of whose birth falls this year. One of the greatest Swedish men of science, comparable in stature with Linnaeus and Berzelius, his ideas on the nature of solutions of electrolytes were first presented in a thesis that earned him—and that only after much argument among his examiners—a fourth-class doctor's degree in the University of Uppsala, a classification so low that it would not normally have allowed him to become a *docent* there. Yet these ideas, developed but not fundamentally altered, were in time recognized to be of such importance as to make him the third Nobel Laureate in chemistry and director of a famous laboratory created in his honour.

Arrhenius, whose name derives from the fact that his forebears lived in the village of Årena, was born at Wijk on 19th February 1859, the son of an estate manager. The following year the family moved to Uppsala, where Arrhenius went to the cathedral school. At the age of seventeen he entered the University of Uppsala. Academically, his early career there was distinguished, and he passed exceptionally quickly the examinations necessary for him to study for his doctorate. Originally he had intended to work under P. T. Cleve, an expert on the rare earths, but gave up this idea when his interest turned towards theory, in which Cleve was not at all interested. In 1881, therefore, he went to Stockholm to work with E. Edlund, then professor of physics at the Swedish Academy of Sciences. His interest in physics was doubtless stimulated by the fact that the rector of the cathedral school was a good teacher of this subject.

After some preliminary work on spark-gap voltages, he turned his attention to the electrical conductivity of solutions. The properties of solutions were then arousing much interest. Van 't Hoff was developing his revolutionary ideas on the analogy between dissolved substances and gases, Kohlrausch was measuring electrolytic conductivities, and Raoult was devising methods for measuring the molecular weights of solutes. Clausius and Williamson were already speculating on the possibility of dissociation in solution. The theory of solutions was engaging the attention of many able chemists: to Arrhenius fell the honour of crystallizing contemporary thought into an important general theory. The association of his ideas with those of Van 't Hoff was particularly significant, for at almost every point they were complementary.

His first important investigation was directed towards finding a method for determining the molecular weights of non-volatile substances, such as sugar, by measuring the extent by which they lowered the electrical conductivity of salt solutions. The method proved useless, but it led him to a detailed investigation of the conductivity of salt solutions generally. There are two fundamental points that have to be explained by any theory of electrolytes. One is that some electrolytes give relatively strongly conducting solutions, whereas others give much more weakly conducting ones. The other is that for all electrolytes the conducting power is relatively greater the greater the dilution. Arrhenius's ultimate answer to this problem was very simple. He postulated that all electrolytes dissociate in solution into positively and negatively charged ions and—in sharp distinction to earlier workers—that these exist in the solution even when no electric current is passing through it. Strong electrolytes he believed to be largely dissociated into ions (we now regard them as completely dissociated) and weak electrolytes relatively less so. For all electrolytes the degree of dissociation increased with dilution.

As has been noted, the ideas expressed in the thesis for his doctorate at Uppsala, submitted in 1883, almost terminated Arrhenius's academic career. At this stage, however, Arrhenius had by no means perfected the theory with which his name is now associated. He realized that dissolved electrolytes existed partly in an active (conducting) and partly in an inactive form, but he did not define what these might be, nor did he specifically refer to dissociation, although this is implicit in his argument.

Fortunately, Arrhenius was not entirely discouraged by the views of his professors, and he sent copies of his thesis to a number of the leading chemists of the day. Among them was Wilhelm Ostwald, then professor of chemistry at Riga, who

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was sufficiently interested to go to Uppsala to discuss the matter with Arrhenius in person. This visit resulted in his getting a junior appointment at Uppsala, doubtless as a result of Ostwald being so impressed by his ability as to offer to get him appointed *docent* at Riga, and this was followed in 1885 by a five-year travelling scholarship from the Swedish Academy of Sciences. This enabled him to travel extensively in Europe and to work with such distinguished men as Van 't Hoff, Ostwald, Boltzmann, and Kohlrausch, all working in the same field. During this time his ideas became clarified and his theory of the ionic dissociation of electrolytes was perfected. The critical year seems to have been 1887. Arrhenius then for the first time saw Van 't Hoff's paper, published in the previous year, in which he expressed the osmotic pressure of solutions in the form $PV=iRT$. Arrhenius quickly identified the i factor as a measure of the dissociation of the solute into ions. Van 't Hoff shared Arrhenius's view, and the two men published their conclusions in 1887 in the first volume of the *Zeitschrift für physikalische Chemie*. Arrhenius related his degree of dissociation α with Van 't Hoff's i factor by the equation

$$i=1+(k-1)\alpha$$

where k is the number of ions into which the molecule of electrolyte dissociates. Ostwald was in agreement, and his great prestige in chemical circles did much to secure recognition for the new theory.

Nevertheless, the theory met with violent opposition in some quarters. Chemical thought at that time was not ready for the idea that in an aqueous solution of common salt, for example, the sodium, which in its ordinary state reacts violently with water, could exist separately from the chlorine. The opposition finally came to a head in 1890. In that year the British Association for the Advancement of Science, meeting at Leeds, held a discussion 'On Theories of Solution', to which the three were invited. Ostwald and Van 't Hoff went to argue in person, and Arrhenius sent a paper. The orthodox view was forcibly put by such men as S. U. Pickering, J. H. Gladstone, and G. F. Fitzgerald, but by the end of the meeting there was no doubt that the new ideas prevailed. With the vindication of his theory, Arrhenius's affairs took a turn for the better, although to his disappointment he was still largely ignored in his own country, to which he was deeply attached. The chair of chemistry at Giessen was offered to him in 1891, but he preferred a lectureship in the technical university in Stockholm. This was converted into a professorship in 1895, but Arrhenius was appointed to it only after much opposition and in the absence of any other suitable candidate. A year later, however, he became Rector. In 1902 he was awarded the Davy Medal of the Royal Society and in 1903 the Nobel Prize for chemistry.

In 1905 the prospect of Arrhenius's leaving Sweden to join Van 't Hoff in Germany led the Swedish Academy of Sciences to found a Nobel Institute for Physical Chemistry. This was in place of two separate institutes that had been planned, one for chemistry and one for physics, and the decision is a measure of the extent to which he had united these two important fields of science. In 1909 Arrhenius, at the age of fifty, began to work there as director and continued almost until his death in 1927.

His later researches covered a wide range: from cosmic physics to glaciology, from immunochemistry to viscosity. In these investigations he was much helped by his wide knowledge, remarkable memory, and ability to see a connection between apparently unrelated facts. In addition, he was a gifted linguist and thus could particularly easily exchange views with colleagues in other countries. Nevertheless, he recognized that this was a fortunate gift not widely bestowed, and he advocated the use of a universal language based on English. He was a well-known expositor of science and author of many popular scientific books which were widely translated.

His later work was by no means unimportant, but it is for the development of the theory of solutions that Arrhenius is most deserving of lasting fame. Apart from the intrinsic importance of his discoveries—their significance in the chemical industry, for example, needs no emphasis—the story of his career forcibly demonstrates that while new ideas demand most searching criticism before they are accepted it is important for this to be objective. This, it may be remarked, is a lesson that not only scientists would do well to learn.

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Lightning

D. J. MALAN

Lightning was studied systematically as early as the eighteenth century, but it was impossible to understand the processes involved until recently, when high-speed cameras and cathode-ray oscillographs became available. The apparatus, and some of the results obtained with it, are discussed in this review of the most important aspects of thunderstorm electricity.

The first systematic investigation of thunderstorm electricity dates from the middle of the eighteenth century, when Benjamin Franklin proved that lightning was an electric spark and that negative electricity was usually involved in a discharge to ground. Although Franklin's experiments were repeated and confirmed, there was no significant advance in the knowledge of lightning until the present century, because a lightning discharge consists of a series of very rapid processes and further progress had to await the development of new experimental techniques. Only such methods as high-speed photography and cathode-ray oscillography could give the high time-resolution required.

The classic work of C. T. R. Wilson and his school from 1916 onwards initiated a new era of discovery in the field of thunderstorm electricity. Appleton, Watson-Watt, and Herd in England, and Norinder in Sweden, were the first to use cathode-ray oscillographs for the study of the fast components of the electrical field changes due to lightning discharges. In the meantime C. V. Boys [1] had invented an ingenious high-speed camera which was used with remarkable success in South Africa by B. F. J. Schonland and his collaborators, who obtained important information on the mechanism of the electrical breakdown in the lightning spark.

The initial discoveries awakened new and world-wide interest in research on lightning and on related problems such as the propagation of atmospherics, radiogoniometry for locating distant thunderstorms, the protection of aircraft and electrical power lines against damage by lightning, and the meteorology of thunderclouds. These and other studies are still continuing, apparatus and techniques have been improved, and the invention of radar gave research workers a powerful new tool for investigating the interiors of thunderclouds.

The erratic occurrence of thunderstorms limits the opportunities for observation, and direct approach by laboratory experiments can be only partly successful as it is impossible to simulate on a small scale the conditions prevailing in large thunderclouds. It might appear that observations made from aircraft could supply a great deal of information about discharges inside thunderclouds. However, lightning is a transient phenomenon, so that the chance that an aircraft, flying at high speed, will traverse the interesting region of the cloud at the right moment is rather remote, and even if it does do so only a relatively small volume of the total region involved in the discharge could be sampled. Aircraft observations have, nevertheless, supplied valuable information about air currents, temperatures, and the distribution of solid and liquid phases of water in various parts of a thundercloud. This information is essential for discovering the process, or combination of processes, by which electricity is generated in the cloud.

There are three main types of lightning discharges: flashes to ground, air discharges, and cloud flashes. Flashes to ground are discharges between a cloud and the ground. They show profuse branching in a downward direction. The altitude of the cloud base lies between 1 and 2 kilometres, but the total length of the visible track of a flash to ground will be greater owing to the tortuous path of the flash. Air discharges are flashes that issue from the cloud and instead of reaching the ground end in space charges in the air. Sometimes air discharges running horizontally below the base of the cloud are as much as 10 miles in length. Cloud flashes, popularly known as sheet lightning, are discharges between charged centres inside the cloud. These discharges cause diffuse illumination of the cloud, and their discharge channels are rarely visible.

Recent investigations by radar have revealed that discharges inside long banks of clouds often extend for 30 and occasionally even for 100 miles [2]. In this type of cloud flash the illumination is seen to start at one end of a long bank of clouds and to travel towards the other. It was formerly

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thought that completely separate and isolated charge centres or cells in the cloud were discharged in succession by the trigger action of the photoelectric and electrostatic effects of the preceding discharge, but radar observations have shown that the discharge is in fact continuous.

HIGH-SPEED PHOTOGRAPHY

Hoffert in 1890 and Walter in 1903 used the simple expedient of rocking an ordinary camera to and fro about a vertical axis to study the structure of lightning flashes. They were able to show that a flash to ground usually consists of a series of discharges following each other at intervals along the same track, and they were also able to detect a pre-discharge before the first stroke. Such apparatus could give only qualitative results. The Boys camera, which represents a very considerable refinement of this idea, has played such an important role in the study of lightning that a short description of it will be given before discussing the results obtained.

Figure 3 shows the combination of cameras used in South Africa by B. F. J. Schonland, D. J. Malan, and H. Collens [3]. The large camera in the centre is the Boys camera. It has two lenses, mounted diametrically opposite each other on a circular disk that is rotated at high speed by a belt drive when the large pulley at the left is turned.

Let us consider what happens when a lightning discharge that starts at the cloud and progresses vertically downwards to ground is photographed. At any instant the lenses of the Boys camera are moving in opposite directions. Thus if the lenses are horizontally opposite each other at the moment when the discharge starts, one lens will be moving downwards and the other upwards. The lens moving downwards, in the direction of advance of the discharge, lengthens the photographic image by an amount equal to the distance moved by the lens during the time the discharge has taken to proceed to the ground. Conversely, the other lens shortens the image by the same amount. The time taken by the discharge to reach the ground can thus be obtained by dividing the difference between the lengths of the images by twice the linear speed of the lenses.

If the lenses are in any other position when the discharge starts, one lens will be moving towards the right and the other towards the left, so that the images of the advancing tip of the lightning discharge will be distorted towards the right and the left respectively. By measuring these distortions it is possible to draw up a timetable of the progress of the lightning flash and to determine in which direction it was going. The lenses of the camera shown in figure 3 are rotated at 50 revolutions per second, making it possible to measure intervals with an accuracy of a few microseconds.

The cameras are usually operated at night so that the lens shutters can remain open while waiting for a flash. Photographs can also be taken in daylight by using the disturbance produced on a radio receiver at the commencement of the lightning flash to operate a relay that opens the camera shutter for a pre-set time. Other cameras have been designed to obtain linear, instead of circular, motion of the lens relative to the film, because the results are then easier to interpret. These have been very useful for studying the slow components of lightning flashes.

When the lightning flash has several consecutive strokes, the lenses of a Boys camera will make more than one revolution during the course of the discharge, so that it is not possible to pick out on the photograph the order of sequence of the strokes. The small camera seen at the top of figure 3 is used to overcome this difficulty. It is similar in construction to the main Boys camera but has only one lens on its disk, which is slowed down, by intermediate belts and pulleys, so as to turn at one revolution per second. As most lightning flashes last for less than a second the images of successive strokes will follow each other in chronological order without overlap. Knowing the speed ratio of the cameras, it is easy to correlate the strokes photographed by the fast camera with those of the slow one. The third camera, appearing at the right in figure 3, is an ordinary camera which is used for obtaining a still picture of the flash. Figure 2 (*a*, *b*) shows a set of photographs taken respectively with the slow and fast cameras of figure 3 of a lightning flash that had seven component strokes following each other in the order 1–7.

RESULTS OF PHOTOGRAPHIC STUDIES

As already stated, flashes to ground may consist of several successive strokes following the same track. At Johannesburg 50 per cent of all flashes have more than four strokes, and flashes having twenty strokes are not uncommon. In England, by contrast, the majority of flashes have only one stroke [4], the difference being evidently due to the greater activity of tropical thunderstorms. Usually only the first stroke has branches (figure 2, stroke 1). The most frequent time interval between strokes is from 30 to 50 milliseconds.

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Each stroke is dual in nature. A faintly luminous discharge, called a leader streamer, issues first from the base of the cloud and proceeds downwards. When it arrives near the ground it is met by a very bright and intense discharge called a return stroke, which sparks over from the ground and travels upwards at high speed along the previously formed leader channel.

The first leader initiates the electrical breakdown between the base of the cloud and the ground and therefore has no prepared track through the air. High-speed photographs show that it advances rapidly for a distance of about 20 metres and then seems to pause. After an interval of about 50 microseconds it suddenly surges ahead a further 20 metres as a relatively bright discharge and pauses again. The intermittent step-like advances are repeated until the leader finally reaches the ground, when the bright return stroke follows. The figures quoted are mean values [3].

Figure 4 shows a Boys camera photograph of such a stepped leader. The lens rotation is from right to left, and the leader steps can be seen to the right of the return stroke, the image of which is considerably widened because its luminosity lasts much longer than that of the leader steps. The diameter of the return-stroke channel is actually very much less than that of the stepped leader, owing to the magnetic pinch effect of its heavy current [13].

The fact that the overall velocity of advance of a stepped leader is remarkably constant suggests that the bright steps are preceded by a faint pilot streamer which advances continuously during the apparently quiescent intervals. When such a pilot streamer has forged ahead a few tens of metres it demands a heavier current, with the result that its luminosity suddenly increases and it appears as a bright step. The presence of this faint pilot streamer advancing at about 2×10^7 cm/sec has been deduced from theoretical reasoning, but it has not yet been demonstrated photographically with complete success.

The discovery of the stepped leader constituted a great advance in understanding how it was possible for a lightning spark to jump the mile-long gap between the cloud and the ground. The total potential is of the order of 100 million volts, and the overall potential gradient is thus only a small fraction of that required for spark breakdown between metal electrodes in the laboratory.

Several theories have been advanced to explain the mechanism of the bright step, notably by B. F. J. Schonland [5] and C. E. R. Bruce [6]. Although they differ somewhat in detail they lead to the same overall conclusion. At the completion of a step a highly conducting path exists between the cloud and the leading tip of the step, so that the potential here is of the same order of magnitude as the cloud potential. The resulting concentration of lines of force at the leader tip makes it possible for a faint pilot streamer to advance a limited distance. However, the intense step discharge that then follows re-establishes a high tip potential, so that the pilot streamer can forge ahead on its next stage. There is no reason why such a step-like discharge, once started, should not go on indefinitely, provided the cloud can supply the necessary charge. This conclusion is supported by the existence of extremely long horizontal air discharges which, as camera studies have shown, advance in stepped-leader fashion.

During the advance of the stepped leader, negative charge is being lowered from the cloud. The pilot streamer on its way to ground forms side branches to concentrations of positive space charge in the air that have originated from point discharge at the ground. The ground, a good conductor, acquires an induced positive charge under the advancing negatively charged leader. When the leader reaches the ground the negative charge distributed along its channel will be neutralized by the return stroke, which can be considered as positive charge moving upwards along the channel and outwards along the branches previously formed by the leader. The luminosity of the return stroke travels upwards at speeds varying from a tenth to a third of the velocity of light.

Figure 1 shows the timetable in microseconds of the progress of a return stroke. Whereas the luminosity takes 71 microseconds to reach the cloud it reaches the lower end of the long branch at the right only after 327 microseconds.

The intense current, of about 30 000 amperes, in the first return stroke causes heavy ionization of the lightning channel, which remains conductive for about 100 milliseconds after the current has stopped flowing. If a second stroke follows within this time interval it thus encounters a prepared path of low resistance along which its leader advances rapidly and continuously in the form of a bright dart, going directly to ground along the original main channel without branching. This dart leader also distributes negative charge along its track and is consequently followed by an intense upward-moving return stroke from the ground; this is similar to the first return stroke but without its branches.

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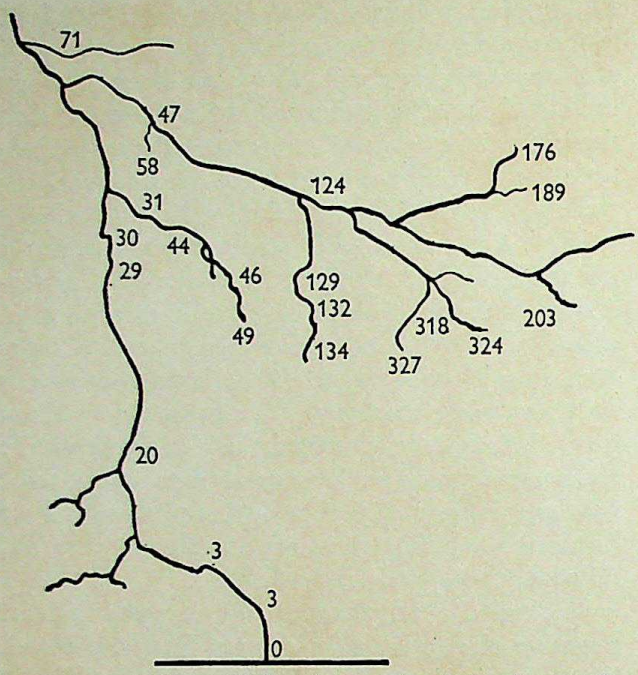

FIGURE 1 – *Timetable in microseconds of the advance of a return stroke towards the cloud and along the branches.*

Other subsequent strokes will also have dart leaders, whose velocities are approximately ten times that of stepped leaders. Figure 5 shows a dart leader at the right and the following return stroke at the left, the motion of the camera lens being from right to left. If the interval that has elapsed since the previous return stroke approaches 100 milliseconds, the ionization remaining in the upper part of the channel is barely sufficient to guide the leader, which then again becomes step-like in nature, the step lengths and intervals being short. By the time the leader reaches it, the lower part of the channel has generally lost its ionization to such an extent that it has no guiding effect at all. The leader then immediately becomes a true stepped leader and follows an independent path in its further advance, and strikes the ground at a different spot from the previous strokes.

THE MAIN CHARGE CENTRES OF THUNDERCLOUDS

By convention, the electric field at the ground caused by a charge in a cloud is considered to be positive when the charge is positive, and negative when the charge is negative. In the case of actual thunderclouds the field is found to be negative when the cloud is near and positive when it is more distant. This effect can be ascribed to the presence of two charged regions one above the other and of opposite polarity, the lower or N region being negatively charged and the upper or P region being positively charged.

A lightning discharge causes a sudden change in electric field. With rare exceptions, flashes to ground always give positive field changes, indicating that the cloud has become less negatively charged and that flashes to ground thus tap the negative or N charge centre and bring negative electricity to earth. Cloud flashes, on the other hand, give positive field changes when the cloud is near the observer and negative field changes when it is distant, from which observation it is concluded that cloud flashes are discharges between the N and the P charge centres. Apart from showing that the positively charged region is higher than the negatively charged region, these general observations give no indication of the actual heights at which these regions are situated.

The change in electric field due to a lightning flash as measured at an observation post on the ground depends on the distance (D) of the flash, the magnitude (Q) of the charge brought to earth or neutralized in the cloud, and the initial height (H) of the charge. D can be found by timing the interval between seeing the lightning and hearing the thunder. It is obvious that the two unknown quantities Q and H cannot be determined from a single observation, but that two independent measurements of the field changes at different distances are required. In the case of cloud flashes between charges at different heights at least three measurements are necessary.

The technique of using a network of observing stations has been tried, but the results have been rather disappointing because the theoretical calculations are based on an assumed spherical distribution of the cloud charges, whereas, as will be shown later, this is far from being so.

DISTRIBUTION OF THE CHARGES

The first direct determination of the heights of the various thundercloud charges is due to G. C. Simpson, F. J. Scrase, and G. D. Robinson [7], who sent up sounding balloons carrying an ingenious apparatus, which they called an altielectrograph, for measuring electric fields. The apparatus consists essentially of a long trailing wire in which a break is made near its top end; the severed ends are connected to electrodes pressing on pole-finding paper. Strong fields cause an electric current to pass between the ends of the wire, and either the upper or the lower electrode will colour the paper, depending on the direction of the field. The paper is moved by a clockwork motor, and the width of the coloured

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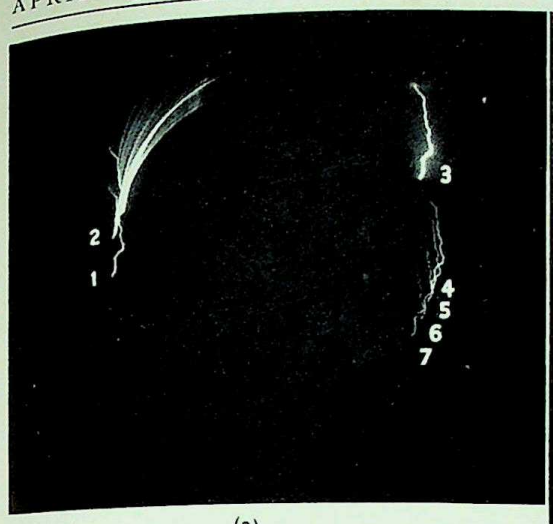
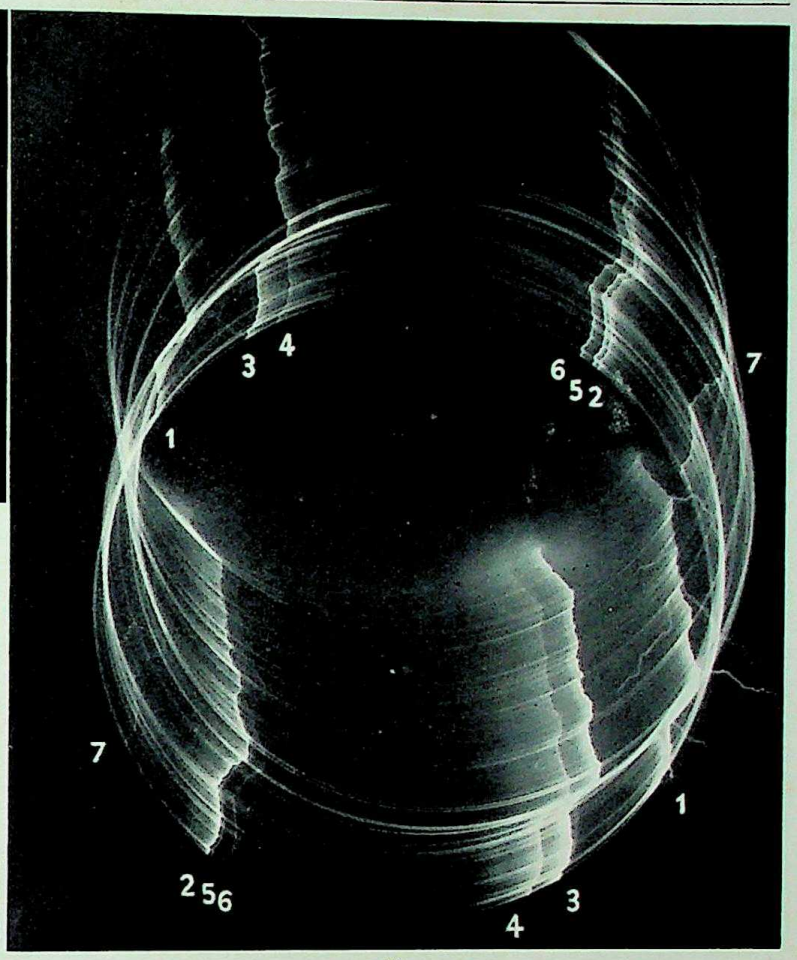


(a)



(b)

FIGURE 2 – (*a*) *Picture of a flash with seven strokes following in order* 1–7 *taken with the slow camera of figure* 3. (*b*) *Picture of the same flash taken with the fast Boys camera having two lenses. Direction of rotation of lenses is clockwise. Only stroke* 1 *has branches.*

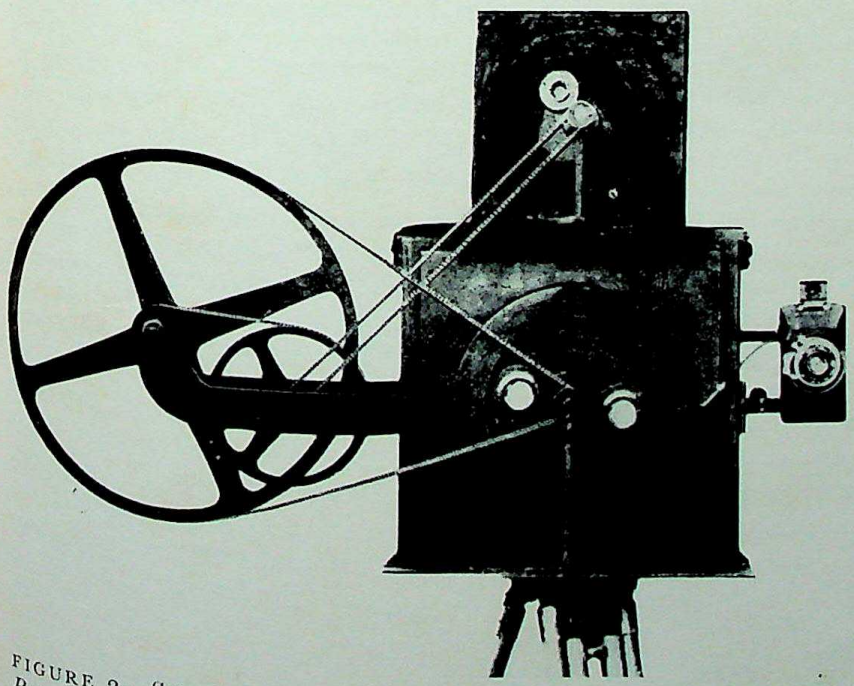


FIGURE 3 – *Set of cameras used in South Africa. Bottom, double-lens fast Boys camera; top, single-lens slow-speed camera; right, still camera.*

trace serves as a measure of the field strength.

These balloon soundings showed that the negative charge centre is situated above the base of the cloud, in a region where the temperature is below 0° C, and that the main positive charge centre is higher up, towards the top of the cloud. These workers also made the important discovery that another small positive charge is often present in the base of the cloud, where the temperature is above 0° C.

The presence of this lower positive (p) charge accounts for the fact that the electric field just before the occurrence of a flash to ground near by is very often found to be quite small or even positive in sign; the small positive charge immediately overhead counteracts the effect of the much larger negative charge higher up. Lightning

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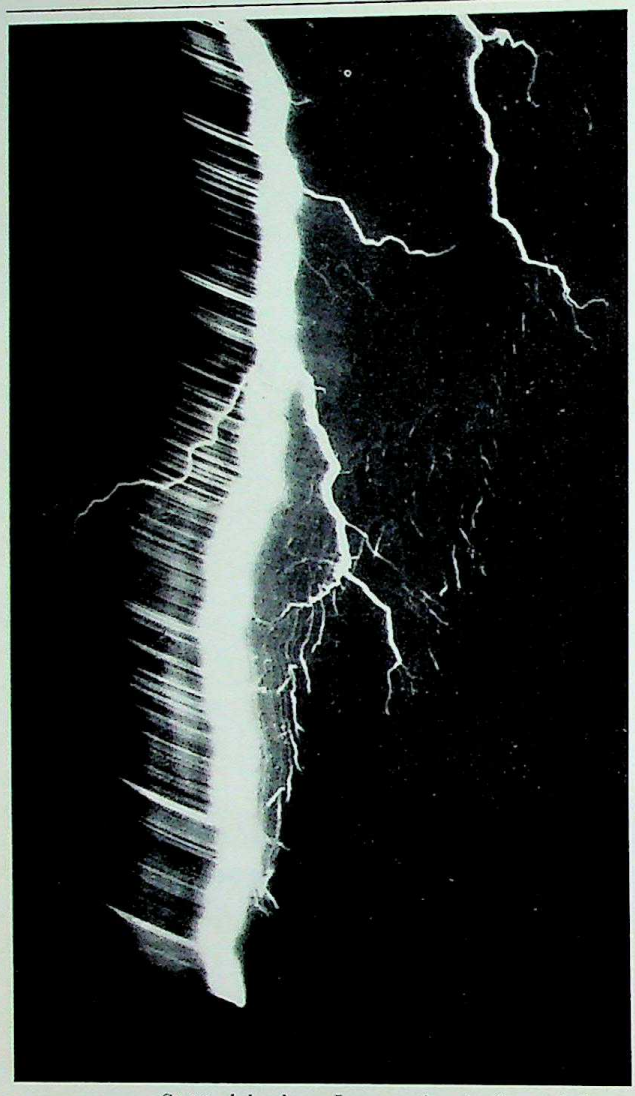

FIGURE 4 – *Stepped leader. Lens motion is from right to left. The step-by-step downward advance of the leader can be seen on the right. The image of the bright return stroke at the left is broadened owing to its continuing luminosity. The horizontal streaks at the left are caused by the uneven fading out of the luminosity due to bends in the channel.*

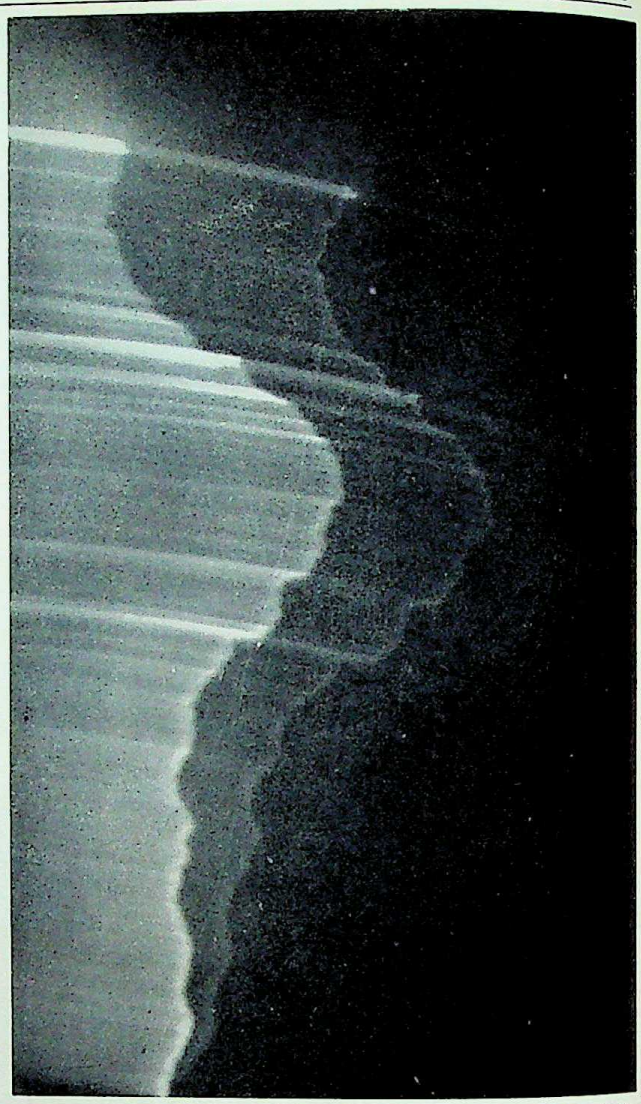

FIGURE 5 – *Dart leader. Lens motion is from right to left. The leader starting at the top right proceeds to ground, where it is followed by the return stroke at the left. The motion of the lens distorts the images and gives the V-shaped picture.*

alarms designed to ring a bell or flash a light when the field is high are thus liable to fail in their prediction when a very near discharge is imminent.

Sounding balloons suffer from the disadvantage that their path of flight cannot be controlled and that the time they take to traverse the cloud is long compared with the duration of the electrical processes. The results obtained are therefore difficult to interpret. For these reasons a different method of investigating the charge distribution was subsequently used in South Africa [8]. It was there shown that it was possible to calculate how the main negative charge is distributed in thunderclouds by examining at ground level the variation with distance of either the electrostatic field changes due to the leader process, or the relative amplitudes of leader and return stroke field changes, or the slow field changes taking place during the intervals between the successive strokes of a flash to ground.

These methods of investigation led to the unexpected discovery that the negative charge is distributed in an approximately vertical column extending from about 3·5 km to 8·5 km altitude. It was found also that the first stroke of a flash to ground tapped a limited region of charge at an altitude of about 3·5 km and that the succeeding strokes tapped progressively higher and higher regions of the negatively charged column. This was a surprising discovery, because it was previously thought that successive strokes tapped completely separate and isolated regions of charge

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distributed horizontally near the base of the cloud.

The whole negative column is in a region of sub-zero temperature, its top often reaching to the −40° C level (figure 6). This temperature has a special significance, because it is the lowest temperature to which a droplet of pure water can be supercooled without freezing. It follows that only ice particles are present above the −40° C level, while both ice particles and water drops can exist in the region of the negative column, a fact which must have some bearing on the physical processes involved in the electrification of the cloud.

The distribution of the electrical charges involved in lightning discharges can also be studied by radar, because the charges in the cloud are tapped by a multitude of discharge streamers which create highly ionized regions from which radar pulses can be reflected. Recent radar studies [9] have confirmed the presence of a high column of negative charge and have further shown that its diameter is about one or two kilometres.

The negative column is associated with a cell or chimney of strong upward air currents in the cloud. Large particles of ice or water which are negatively charged tend to fall downwards under gravity, while smaller particles which are positively charged are blown upwards to form the upper positive charge, as will be explained later. It is likely that some of the light positive particles spill over the top of the chimney of updraught and are carried to lower altitudes by the downdraughts existing towards the rear of a fully developed thundercloud. This conclusion is confirmed by radar observations, which show that discharges inside the cloud between the *N* and *P* charge centres very often fail to reach the same altitude as the final strokes of flashes to ground, showing that all the *P* charge is not wholly above the negative column.

Figure 6 illustrates the probable distribution of the charges in a thundercloud cell, taking into account all the information available at present. A large thundercloud may contain several active cells. At Johannesburg, which lies on a plateau 1800 metres above mean sea level, the tops of thunderclouds reach altitudes of 12 000 metres above ground level. In more temperate latitudes the clouds generally do not reach such a great height, so that the negative column may possibly be somewhat shorter in vertical extent.

ELECTRICAL BREAKDOWN PROCESSES IN THE CLOUD

The electrically charged regions of a thundercloud contain numbers of water drops and ice particles which carry charges but are insulated from each other by the intervening air. Such a region cannot be discharged before electrical contact is established between the individual charged particles so as to collect and converge their charges into a conducting ionized channel that can then forge ahead as a lightning flash. The following explanation of the mechanism by which such a conducting channel is formed in the case of a flash to ground was first suggested by L. B. Loeb [10] from theoretical reasoning. His predictions were subsequently confirmed by the experimental work of N. D. Clarence and D. J. Malan [11].

The region between the bottom of the negative column *N* and the lower positive charge *p* (figure 6) in the base of the cloud contains large water drops in a growing electric field. A positive charge is induced on the upper and a negative charge on the lower surface of each drop, which becomes elongated on account of the opposing electrical attractions of the *N* and the *p* cloud charges.

As the charges in the cloud build up, the field increases and the drops get longer and longer until the field reaches a value of 10^4 volts/cm. At this stage a drop becomes unstable and a long water

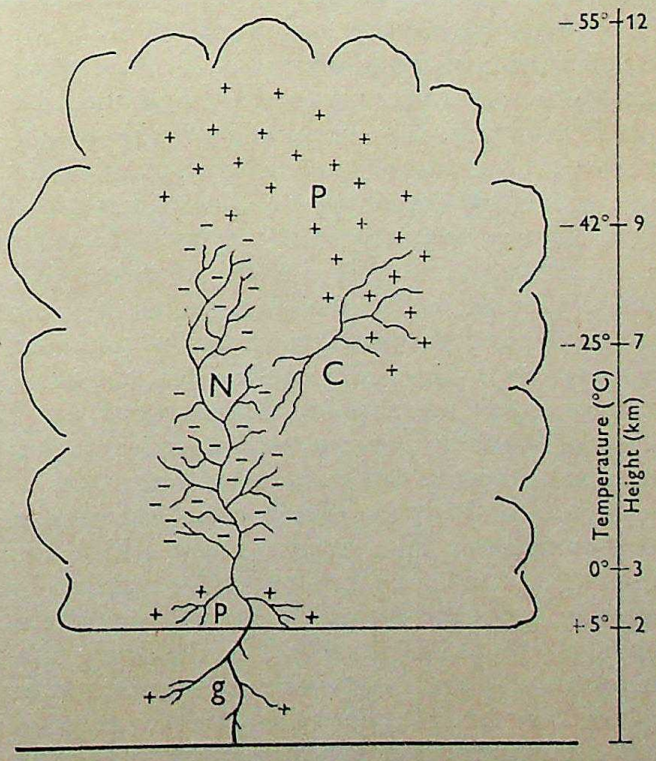

FIGURE 6 – *Probable distribution of the main charges in a thundercloud at Johannesburg, altitude* 6000 *ft above mean sea level.* P, *upper positive charge;* N, *negative column;* p, *lower positive charge;* g, *flash to ground which taps the negative column in stages from its base upwards;* C, *cloud flash between the* N *and* P *regions.*

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filament shoots out from its positive end; a glow discharge starts at the fine tip of this filament, which then breaks up, leaving a spray of minute charged droplets and ions. The drop will continue shooting off filaments until its diameter is reduced to 1 mm [12]. It needs only one propitiously placed drop in the cloud to initiate spraying, which then spreads from drop to drop in a chain reaction until a conducting channel is established between the N and the p charge centres. This completes the first stage of the electrical breakdown process.

Neutralization of the p charge now follows, after which the conducting channel extending to the base of the cloud becomes negatively charged, the negative charge being supplied by streamers radiating into and tapping the negative column. As charging continues, the electric field in front of the lower tip of the conducting channel keeps on rising until it reaches 6×10^4 volts/cm, which is the field required [5] for starting off the pilot streamer and stepped leader breakdown through the air towards the ground.

THE REASON FOR MULTIPLE STROKES

The charge distribution in the negative column is continuous but not of uniform density. It would have been expected that such a column of charge should discharge continuously once the leader has established electrical contact with the ground, and not intermittently in a series of strokes as usually happens. The answer to this perplexing riddle was found by examining the slow electrostatic field changes occurring in the intervals between the successive strokes of a flash to ground [8]. These junction, or J, field changes, as they are called, showed that positive charge was moving upwards at the rate of 3×10^6 cm/sec and being neutralized in the process. The stages of the J process occurring between two successive strokes of a flash to ground are illustrated in figures 7(a, b).

Figure 7a shows the distribution of charges at the completion of a return stroke which has brought a positive charge $+q$ to the highly conducting branched streamers at the top of the channel at a mean height H_1. In the strong field between $+q$ and $-Q$ positive streamers start penetrating into $-Q$ until the positive charge $+q$ has been neutralized, leaving a residual negative charge $-(Q-q)$ in a region which has been made conducting by the streamers at a mean height H_2, shown at b.

This negative charge now flows down the channel as a dart leader as shown at c. The return

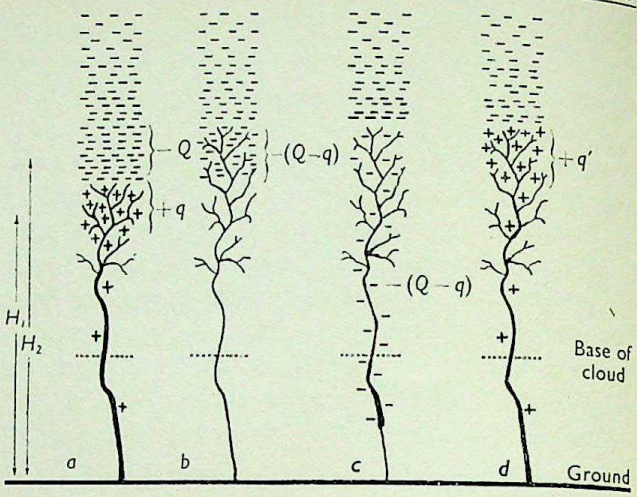

FIGURE 7 – *Diagram showing the electrical processes taking place in the cloud during the interval between two successive strokes of a flash to ground.*

stroke which follows again brings a positive charge to the top of the channel as shown at d. Conditions are now similar to those at a. The whole J process is successively repeated, draining higher and higher regions of the negative column until its charge is exhausted. Investigations by means of radar [9] have shown that in addition to the J processes at the top of the channel, illustrated in figure 7, the mopping up of residual negative charges lower down in the cloud continues throughout the flash.

Since flashes which have only one or two strokes are often followed by a continuous current to ground of 50–80 amperes lasting for a few hundred milliseconds, it has been suggested that in these cases the negative column is drained in a continuous fashion because the density of its charge distribution is exceptionally high, due to as yet unknown meteorological factors. This type of flash is more likely to ignite an inflammable structure or to set fire to a forest than the intermittent type of flash, each stroke of which passes a much heavier current, of explosive violence, but lasts only for some microseconds.

ELECTRIFICATION PROCESSES

Until about twelve years ago it was thought that the falling drop electrification theory of C. T. R. Wilson could account for the separation of the main positive and negative charges in a thundercloud. According to this theory a large water drop in a cloud will have an induced positive charge on its lower surface and a negative charge on its upper surface, due to the normal electric field. The drop is supported, or slowly falls, in a strong upward air current, the air

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normally containing approximately equal numbers of negative and positive ions. When a negative ion is blown towards the drop it will be attracted by the spatially lower positive charge and will attach itself to the drop. A positive ion, on the other hand, will be pushed aside and will have to go round the drop before it comes into the field of attraction of the negative charge on the upper surface of the drop. The mobility of positive ions is, however, low compared with the wind velocity, with the result that they will be unable to turn back to the drop but will be blown past. By this selective capture of negative ions the drops become negatively charged and form the lower negative or *N* charge centre. The air which is blown upwards will remain with an excess of positive ions, which go to form the upper positive or *P* charge centre. However, when more data became available about the life history of thunderstorm cells it was found that the Wilson process alone was too slow to produce the observed charge separation in the available time.

A thundercloud contains water vapour, large and small water drops, and large and small ice particles—some dry and some wet. The drops and ice particles have widely varying temperatures, and are in a state of turmoil, caused by the strong air currents in the cloud. Laboratory experiments have shown that electrical charges can be separated by various reactions between the different constituents of the cloud.

Friction between ice particles of different size generates electricity, but the reaction depends upon the difference in temperature between the colliding particles and also on their state of contamination by dissolved substances. It does not therefore lend itself to quantitative estimation.

When an ice particle grows by sublimation from water vapour it may give off small splinters of ice, the main particle acquiring a negative and the splinters a positive charge. The splashing produced when a large drop of water collides with a hailstone and becomes partly frozen to it gives a negative charge to the hailstone and a positive charge to the spray of droplets.

When small supercooled droplets impinge on an ice particle they get frozen on to the particle, which then acquires a negative charge, and the air becomes positively charged. Some support for considering such a riming process as at least partly responsible for the charge separation in thunderclouds is found in the observation, already noted, that the negative column of charge extends to the $-40°$ C level, above which height water cannot exist in liquid form, and riming is thus impossible. Any of these processes of charge generation causes negative charge to be collected on the larger and positive charge on the smaller particles, so that separation of the respective charges can be effected by gravity. The heavier and negatively charged particles will tend to fall downwards, whereas the lighter ones will be carried towards the top of the cloud by updraughts.

A number of other explanations for the electrification of thunderclouds have been advanced, but points of objection can be raised against all existing theories.

The origin of the small positive charge in the base of the cloud is less obscure, and it seems fairly certain that there are two contributing processes. Firstly, positive ions due to point discharge at the ground are carried upwards by rising air currents into the base of the cloud, where they become attached to, and immobilized by, the water drops. Secondly, large drops in the base of the cloud tend to be shattered by the updraughts, and by virtue of the waterfall effect the resulting debris of smaller drops acquires a positive charge.

In conclusion, a thundercloud may be likened to an enormous witch's cauldron of which we now know the ingredients and the final products. Much more information will have to be forthcoming, however, before the connection between the two is fully understood.

REFERENCES

[1] Boys, C. V. *Nature, Lond.*, **118**, 749, 1926.
[2] Ligda, M. G. H. *J. atmos. terr. Phys.*, **9**, 329, 1956.
[3] Schonland, B. F. J., Malan, D. J., and Collens, H. *Proc. roy. Soc., A*, **168**, 455, 1938.
[4] Pierce, E. T. *Quart. J.R. met. Soc.*, **81**, 211, 1955.
[5] Schonland, B. F. J. *Proc. roy. Soc., A*, **164**, 132, 1938; **220**, 25, 1953.
[6] Bruce, C. E. R. *Ibid.*, **183**, 228, 1944.
[7] Simpson, G. C. and Scrase, F. J. *Ibid.*, **161**, 309, 1937.
Simpson, G. C. and Robinson, G. D. *Ibid.*, **177**, 281, 1940.
[8] Malan, D. J. and Schonland, B. F. J. *Ibid.*, **206**, 145, 1951; **209**, 158, 1951.
[9] Hewitt, F. J. *Proc. phys. Soc. Lond., B*, **70**, 961, 1957.
Miles, V. G. *J. atmos. terr. Phys.*, **3**, 258, 1953.
[10] Loeb, L. B. Report, Dept. Physics, University of California, 1953.
[11] Clarence, N. D. and Malan, D. J. *Quart. J.R. met. Soc.*, **83**, 161, 1957.
[12] Macky, W. A. *Proc. roy. Soc., A*, **133**, 565, 1931.
[13] Allen, J. E. *Endeavour*, **17**, 117, 1958.

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Fourcroy and the anti-phlogistic theory

W. A. SMEATON

The overthrow of the phlogiston theory was of profound importance to the history of science. The chief credit must go to Lavoisier, but it is not always realized that his ideas were long opposed. That they ultimately became generally accepted is due in large measure to Fourcroy, through his dispassionate and brilliant assessment of the evidence. Marat sneered at Fourcroy as Lavoisier's 'little disciple, who propagates these fine theories in the four corners of Paris', not recognizing this as one of the most important scientific tasks of the day.

Antoine François de Fourcroy was born in Paris on 15th June 1755 and became a medical student there about 1773, when Lavoisier was beginning his great series of researches on combustion and calcination. From his earliest teachers of chemistry Fourcroy doubtless learned that all inflammable substances and metals contained phlogiston, a 'principle' that was emitted during combustion and calcination and was transferred from one substance to another in many reactions. Fifteen years later, he himself taught that nothing was emitted during combustion, but that combustible materials combined with oxygen, one of the constituents of the atmosphere. These are the fundamental statements of two great systems of chemistry. The difference between them is profound. Phlogiston was a principle that could never be obtained in isolation, and to which contradictory properties were assigned by different chemists. By contrast the anti-phlogistic theory was based on the study of a substance that could be isolated, weighed, and examined by ordinary chemical and physical means.

The experimental discoveries of many scientists contributed to this revolution in chemistry, but credit for the foundation of the anti-phlogistic theory belongs to Lavoisier, who gradually built it up in a long series of papers published from 1773 to 1787. Lavoisier's writings were read by those who consulted the scientific journals, but his work was widely known outside scientific circles, and after the new theory was perfected it spread rapidly throughout the world. It was Fourcroy who was mainly responsible for this wide dissemination of the anti-phlogistic theory.

Fourcroy's family was not rich; after leaving school he became a clerk, and might have remained in obscurity if he had not met F. Vicq d'Azyr (1748–94), who was beginning his career as a doctor and anatomist. Vicq d'Azyr was impressed by the young clerk and persuaded his father to allow him to study medicine. A brilliant student, Fourcroy received much encouragement and financial support from the members of the *Société Royale de Médecine*, of which Vicq d'Azyr was secretary. Most of the members were young doctors interested in the scientific aspects of medicine, and among them was J. B. M. Bucquet (1746–80), professor of chemistry in the Faculty of Medicine in Paris.

Following Vicq d'Azyr, Fourcroy was at first interested in anatomical research, but Bucquet's influence became stronger, and he soon decided to concentrate on chemical research and teaching [1]. He worked in Bucquet's laboratory, and began his career as a lecturer one day in 1778 by taking Bucquet's place when the latter was ill [2].

In the winter of 1778–79, before he had graduated, Fourcroy gave his first annual course of lectures, in which he adopted Bucquet's method of combining chemistry and natural history. He soon became known as an excellent lecturer, and his reputation was increased by the appearance in 1782 of his first book, *Leçons élémentaires d'histoire naturelle et de chimie*, which was translated into English and Italian. After Bucquet's death in 1780 Fourcroy would have been a worthy successor to his chair, but by his close association with the *Société Royale de Médecine* he had incurred the disfavour of the senior members of the Faculty, who were opposed to certain activities of the *Société*. On graduating in 1780 he was refused the title of *docteur régent*, without which he could not teach in the Faculty. This may ultimately have been to Fourcroy's advantage, for he had as a result to develop courses dealing with all branches of chemistry, while as professor in the Faculty he might have concentrated on the medical aspects of the subject.

In his last years Bucquet carried out much research in collaboration with Lavoisier, and was

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probably the first chemist to adopt Lavoisier's theory, which he taught in his final courses of lectures [3]. Fourcroy took part in some of this joint research, and he too favoured Lavoisier's theory as early as December 1777, when, after reviewing the history of the theory that metallic calces contain air, he wrote: 'Finally, by many experiments which are as ingenious as they are exact, M. Lavoisier showed that calcination is nothing but the absorption by the metal of an elastic fluid contained in the air, and that the reduction of a metallic calx is only the release of this fluid. . . .' [4].

In a medical thesis presented on 15th June 1778 Fourcroy [5] also stated that the illustrious Lavoisier had proved that air is a mixture of two gases. By 1782, nevertheless, he was no longer convinced that Lavoisier was correct in rejecting phlogiston. In the preface to the *Leçons élémentaires* Fourcroy explained that one of his objects was to compare the phlogistic and the new theories, declaring that he neither rejected the one nor adopted the other. He stated that he considered Lavoisier's theory to be the more convincing at that moment, since it appeared to proceed solely from confirmed facts. The new theory was still far from perfect in 1782, and Fourcroy thought that many phenomena were better explained by P.-J. Macquer (1718–84). In 1777, in the second edition of his *Dictionnaire de chimie* [6], Macquer had expressed the opinion that during combustion and calcination the absorption of part of the air was accompanied by the emission of phlogiston, which he considered to be identical with light. This theory too had its defects; Fourcroy pointed out, for example, that some metals could be calcined without visibly emitting light.

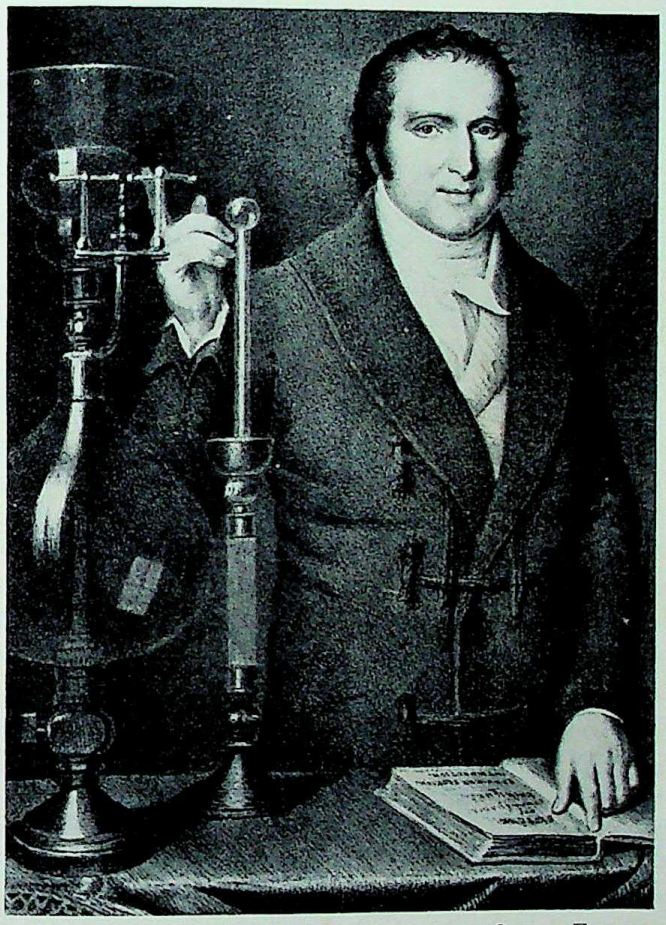

FIGURE 1 – *A. F. de Fourcroy*, 1755–1809. *From a lithograph by Bonhomme, after a portrait by David. (By courtesy of the Bibliothèque Nationale, Paris.)*

The uncertainty about the origin of the light emitted during combustion was perhaps the chief reason why Fourcroy in 1782 could not wholeheartedly adopt the theories of either Lavoisier or Macquer. Five years earlier he had accepted the theory that air, or a part of the air, was absorbed, but since then Lavoisier had advanced the theory that the matter of fire or light (a weightless fluid, which he later called caloric) was present in all gases, and was released from oxygen during combustion. Fourcroy considered that the presence of fire or light in oxygen was no more proved than the presence of phlogiston in combustibles. It was not until the caloric theory had been put on a quantitative basis, and considerably modified, as a result of the researches on calorimetry by Lavoisier and Laplace, that Fourcroy was able to accept this part of the anti-phlogistic theory.

A note written in 1785 shows [7] that Lavoisier appreciated Fourcroy's book. In this the new theory, at a crucial stage in its development, was presented to a large number of readers and criticized with an impartiality that was rare in eighteenth-century textbooks, and indeed in the textbooks of any century.

The private courses given in Paris by Fourcroy and some of his contemporaries were attended by only small numbers of serious students, but audiences running into hundreds came to hear Macquer's public courses at the *Jardin du Roi* (now the *Muséum d'Histoire Naturelle*). After Macquer's death in 1784 there were two candidates for the chair—Fourcroy and Berthollet (1748–1822). Berthollet was the older man and a member of the *Académie des Sciences*, but Fourcroy, with his considerable reputation as a lecturer, was preferred. Berthollet, who was much interested in the industrial applications of chemistry, successfully filled

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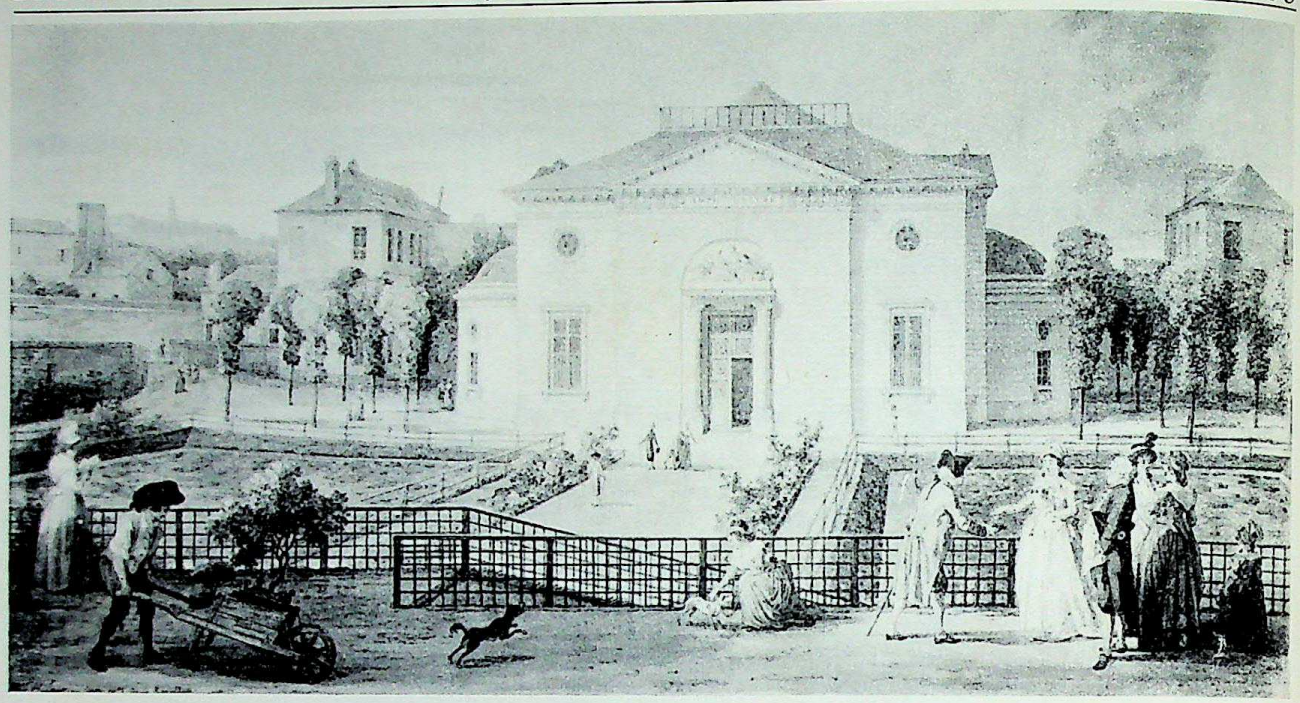

FIGURE 2 – *The amphitheatre of the Muséum d'Histoire Naturelle in* 1795, *from a painting by B. Hilair. (By courtesy of the Bibliothèque Nationale, Paris.)*

Macquer's other post as director of the Gobelins dyeworks.

Soon after his appointment Fourcroy pointed out to a friend that at the Gobelins works Berthollet occupied the best-paid scientific post in France, with an annual salary of 6000 livres, while he himself earned only 1500 livres at the *Jardin du Roi*. He contrasted these figures with the emoluments of high government officials, who sometimes received as much as 100 000 livres, and complained bitterly that scientists were not well enough paid [8]. Fourcroy's books and his private courses added considerably to his income, but it was not until after 1800, when he was a Councillor of State, that he became a fairly rich man.

A new amphitheatre, with room for 1200 people, was built at the *Jardin du Roi* in 1788, and it was in this building that Fourcroy achieved fame. For a quarter of a century very large audiences from all lands were inspired by the great teacher who was also a great orator. Fourcroy came to the *Jardin du Roi* at a time when chemistry was being rewritten; fortunate indeed were those who could follow its progress from his lips.

On 31st July 1784 Fourcroy asked the *Académie* to approve the manuscript of the second edition of his textbook, now called *Elémens d'histoire naturelle et de chimie*. In this he again compared the phlogistic and anti-phlogistic theories, without definitely adopting either. It was not until 9th July 1786 that the report on the work was presented to the *Académie* by Lavoisier and Sage, and when published shortly afterwards the book contained a long preliminary discourse, in which Fourcroy showed that he now completely accepted the anti-phlogistic theory. During the intervening two years the new theory had been greatly strengthened by the discovery of the composition of water and of nitric acid. Moreover, in May 1785 Fourcroy had been elected to the *Académie* and brought into regular contact with Lavoisier and with Berthollet, who was converted some time before Fourcroy.

In April 1786, probably just after his acceptance of the new theory, Fourcroy gave for the first time a short course on the chemistry of gases, which served as an introduction to his general chemistry course. His friend Bouvier wrote out the contents of the course, and the manuscript was revised each year, sometimes by Fourcroy himself, as the lectures were modified to include the latest discoveries concerning gases. Fourcroy intended to publish the course when the subject had reached a fairly steady state, but this was never done. The manuscript shows that the course was a very useful introduction to anti-phlogistic chemistry, and provides further evidence of Fourcroy's skill in presenting his subject in an original and interesting manner [9].

Early in 1787 Lavoisier and his converts were joined by L. B. Guyton de Morveau (1737–1816), who in 1782 had presented a partial reform of

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chemical nomenclature. Fourcroy collaborated with de Morveau, Lavoisier, and Berthollet in preparing a comprehensive system of nomenclature, in which the name of each substance expressed its composition according to the new theory [10]. Fourcroy's contribution was small, but he greatly helped to bring about the rapid adoption of the new nomenclature by using it in the many books that he subsequently wrote.

The first of these was *Principes de chimie*, published in 1787 as part of the *Bibliothèque universelle des dames*. This little book, though elementary, is of considerable interest, for it was the first to be written entirely according to the new theory. Phlogiston was not even mentioned, only the new nomenclature was used, and the contents were systematically arranged according to the composition of the substances discussed. A suitable introductory textbook for any student, it was reprinted in 1787. In 1788 Fourcroy had some copies reissued, with a different title-page and preface, for the students of the Veterinary College at Alfort, where he had been professor of chemistry from 1783 to 1787.

The subject-matter was better arranged in the *Principes de chimie* than in the *Elémens*, where substances were classified according to their mode of occurrence in nature. Fourcroy realized that the new method was superior, but did not use it in the new editions of the *Elémens* published in 1789 and 1791 and reprinted twice in 1793, probably because he or his publisher was unwilling to make a fundamental change in a book that was still selling well. There was a very great interest in the new chemistry in Paris, and Fourcroy taught it not only by means of his books and his lectures at his laboratory and the *Jardin du Roi*, but also in the *Lycée* of the rue de Valois, a private institution for higher education in which he occupied the chair of chemistry from 1787 until 1807 [11].

Fourcroy's activities were sarcastically described in a bitter criticism of members of the *Académie des Sciences* published in 1791 by J. P. Marat, the revolutionary leader. Marat had a long-standing grudge against the *Académie*, which had not given its approval to his scientific publications. An attack on Lavoisier and his work was followed by a description of Fourcroy as 'his little disciple, who propagates these fine discoveries in the four corners of Paris' [12]. But the revolutionary politicians rapidly changed their opinions, and it was after being nominated by Marat that Fourcroy was somewhat reluctantly elected in 1792 as a substitute deputy to the National Convention, the republican parliament. Ironically, when he entered the Convention in July 1793 it was to occupy the seat left vacant by the murder of Marat.

Fourcroy added to his burden of work by undertaking the great task of completing the chemical section of the *Encyclopédie méthodique*, which was intended to replace Diderot's *Encyclopédie*. The first of the six chemical volumes was written by de Morveau, but in 1790 he was appointed to an important administrative post and temporarily abandoned his scientific work. Fourcroy was able to publish the second volume in 1792, but many delays were caused by the Revolution. The sixth volume, completed by N.-L. Vauquelin (1763–1829) after Fourcroy's death, did not appear until 1815.

A systematic teacher, Fourcroy was always trying to find the first principles of chemistry and arrange them in a methodical way, and in the second volume of the *Encyclopédie méthodique* he included an article, '*Axiomes*', in which he classified the chief facts of chemistry under twelve headings. This article, of about 25 000 words, was reprinted in the same year as a small volume entitled *Philosophie chimique*. Under each heading Fourcroy gave a very clear, but necessarily brief, account of the substance or phenomenon named. Each account consisted of a series of propositions, with no suggestion that any of them might be controversial. This book was written in a very concise style, in marked contrast to some of Fourcroy's writings, which were often verbose, even by eighteenth-century standards.

For the details of chemistry it was necessary to consult a book of the conventional sort, but as a guide for the student, or for the older chemist who was uncertain of the anti-phlogistic theory, the *Philosophie chimique* was without a rival. It enjoyed a success that astonished its author. By 1799 about 8000 copies of the two official Paris editions had been sold, as well as pirated copies. However, in a letter to J. B. A. Scherer, Fourcroy said that he had made little financial profit because he had deliberately kept the price low at a time when paper was very expensive [13].

Between 1793 and 1797, when he was active in politics, Fourcroy did little research and wrote no new books, but he worked very hard in promoting the applications of science to the industry and war effort of the young republic, and in developing advanced scientific and technical education. He played a large part in the foundation in Paris of the *Ecole Polytechnique* and the *Ecole de Médecine*, and in each of these he occupied a chair of chemistry

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which he retained, with that in the *Muséum d'Histoire Naturelle*, until his death. He was also largely responsible for the effort to introduce serious scientific courses into the secondary schools [14].

Fourcroy resumed all his scientific work in 1797, and until his death on 16th December 1809 he performed a great deal of useful research, mainly in collaboration with Vauquelin, his former student. His chief interests were the chemistry of animal substances and the applications of chemistry to medicine.

The third chemical volume of the *Encyclopédie méthodique* appeared in 1797, and in this Fourcroy included a great article, entitled simply '*Chimie*', in which he gave a long account of the history of the subject. The chemistry of the late seventeenth and eighteenth centuries required 387 closely printed quarto pages. This account remains to this day an extremely valuable source of information, particularly for the development of the anti-phlogistic theory, for which Lavoisier was given the full credit. However, it is noteworthy that although Fourcroy was the leading exponent of the anti-phlogistic theory, he considered Stahl, the founder of the phlogistic theory, to be the father of chemistry, for he had given the subject its first great unifying theory.

Fourcroy also wrote a completely new treatise, *Système des connaissances chimiques*, which was published in 1800 in editions of ten octavo and five quarto volumes respectively. This great work, not intended for beginners, contained a vast amount of information about the chemistry of all known substances, systematically arranged according to their composition; but it was regarded by Fourcroy only as the first part of a much larger work, and was intended to be followed by three further treatises concerning the history, the practice, and the applications of chemistry. This project was never completed, but in the *Connaissances chimiques* Fourcroy included many references to the history and applications of chemistry. A summary of the work was published by Fourcroy in the form of a series of tables, entitled *Tableaux synoptiques de chimie*, which, like the *Connaissances chimiques*, was translated into several languages.

In 1800 Fourcroy became a member of Bonaparte's Council of State. He was soon appointed Director-General of Public Instruction, and again spent much of his time organizing the educational system. He continued his lecturing and research, in collaboration with Vauquelin, but wrote no new books. However, he found time to publish an enlarged edition of the *Philosophie chimique*, which was printed three times in 1806. Various editions of this work were translated into eleven foreign languages, and students in all countries from Brazil to Russia obtained from it their introduction to the anti-phlogistic system of chemistry.

The many translations of Fourcroy's books show that his influence was greater than that of any other chemical writer of the day. English translations were particularly numerous. All the editions of the *Elémens*, the second and third editions of *Philosophie chimique*, the *Système des connaissances chimiques*, and the *Tableaux synoptiques* were published in London or Edinburgh, and they must have been the books most commonly used by English and Scottish students until the appearance of Thomas Thomson's 'System of Chemistry' in 1802. Another country where Fourcroy's influence was strong was Italy, where at least five translations of *Philosophie chimique* were published.

Fourcroy's books deserved their popularity. As a propagandist for the anti-phlogistic theory he had no rivals, and it is remarkable that he was able to combine his lecturing and writing with his research, which was by no means insignificant, and with a very active public life.

ACKNOWLEDGMENT

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REFERENCES

[1] Palisot de Beauvois. 'Eloge historique de M. Fourcroy', Paris. n.d.
[2] Cuvier, G. 'Eloge historique d'A. F. de Fourcroy'. *Mém. Inst.*, xcvii, 1810.
[3] Smeaton, W. A. *Ann. Sci.*, **12**, 231, 1956.
[4] Fourcroy, A. F. de. 'Mémoires et observations de chimie', p. 31. Paris, 1784. The quoted passage was written in 1777.
[5] *Idem.* 'De utilitate effluviorum elasticorum gas dictorum ad tuendam sanitatem'. Paris, 1778.
[6] McKie, D. *Endeavour*, **16**, 133, 1957.
[7] Lavoisier, A. L. 'Œuvres', Vol. iv, p. 419. Paris, 1868.
[8] Perroud, C. 'Lettres de Madame Roland', Vol. i, p. 374. Paris, 1900.
[9] Fourcroy, A. F. de. 'Cours sur les fluides élastiques en 12 leçons', Bibliothèque publique de Dole, MS. 171.
[10] Smeaton, W. A. *Ann. Sci.*, **10**, 87, 1954.
[11] *Idem. Ibid.*, **11**, 257, 1956.
[12] Marat, J. P. 'Les charlatans modernes, ou lettres sur le charlatanisme académique', p. 37. Paris, 1791.
[13] Fourcroy, A. F. de. *Allg. J. Chem.*, **2**, 478, 1799.
[14] Smeaton, W. A. *J. Inst. Chem.*, **82**, 650, 1958.

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Salt marshes

J. A. STEERS

Salt marshes—and mangrove swamps, which are their tropical equivalents—are areas of natural land reclamation. Geographical and ecological changes occur extensively and very rapidly in them. This article describes the changes in land structure and vegetation as they occur both on the coasts of Britain and America and in the mangrove swamps.

In the shallow waters of many marine inlets, and especially behind sand and shingle bars, conditions are often favourable to the deposition and accumulation of thick deposits of mud and salt. Algae and higher plants begin to colonize the mud flats and a carpet of vegetation spreads over large areas. The plants themselves collect silt, and so there is an interaction of physical and ecological factors at all stages in the development of a marsh. The nature of the plant cover depends in part upon the kind of deposit that is laid down, which may be sand or mud. Plant growth is also closely connected with tidal conditions. At high water of spring tides the whole marsh is covered, but it is exposed at low water. During neap tides, when the range of movement is less, the higher parts of a marsh are not covered, but the low parts may remain submerged for several days. The incidence of flooding tides at certain times of the year is an important factor in the distribution of seeds. In tropical areas the mangrove swamp is the counterpart of the salt marsh of temperate latitudes, and again its spread leads to the formation of new land.

The marshes on the east coast of Britain are usually characterized by thick and fairly compact mud based on sand flats. On the coast of Wales there is far less mud, and the marshes are predominantly sandy. On the south coast many marshes are built up of soft mud and may be treacherous.

Two of our best-studied marshlands are those on the Norfolk coast and those in the Dovey (Dyfi) estuary. Along the Norfolk coast between Hunstanton and Weybourne the water is shallow, and bars of sand and shingle have formed offshore. Scolt Head Island and Blakeney Point are the two best known. Behind the bars there are areas of quiet water in which sediment, carried by the tides, is deposited. The spits and bars are complex structures, having on their landward sides several lateral ridges or hooks. Thus the protected area within is further subdivided.

Scolt Head Island (figures 1–13) shows the stages of marsh growth very well. The island consists of a main shingle ridge with laterals, all built on sand flats. Sand dunes have later formed on these ridges. The island has grown from east to west, although storms may occasionally cut off parts of its western end. At this end there are the newest shingle ridges, enclosing bare sand flats just beginning to show the first stages of marsh formation. The tide ebbs and flows over them and carries a large amount of fine material in suspension. Some of this is dropped near the limits to which the water reaches, some around patches or rolls of seaweed; lugworm (*Arenicola*) casts may cause local deposition, and some material falls on the slightly higher parts of the sand flats. For a few years there may be little noticeable change, but in course of time the patches of mud, as the result of their outward and upward growth, begin to form ill-defined islands. Seeds reach them, carried by water, by birds, and often by man, and under appropriate conditions plant growth begins. On a substratum of sandy mud *Salicornia* (samphire) and *Suaeda maritima* (herbaceous seablite) or locally *Puccinellia maritima* (sea poa) are most likely to be the pioneers. On soft and wet mud *Zostera* species are usually the first arrivals. The plants themselves soon become obstructions and induce further deposition, and, gradually, the tide is more and more enclosed between ill-defined mud banks partly covered with plants. As the banks grow higher and unite, the water is increasingly confined to the embryo creeks.

The drainage pattern of a marsh is best seen from the air (figure 13). The creeks, unlike rivers, have not cut their valleys; they are unenclosed parts of the surface on which marsh has grown. Their pattern is complex, but is like that of a river system, since there are major creeks into which a large number of winding tributaries drain. The bottoms of the creeks, especially of the larger ones, are part of the substratum. As the marsh grows upwards, fewer tides cover all of it, and this affects the spread of vegetation. A walk from the lower

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to the upper levels of a typical Norfolk marsh shows this. The bare mud flats with algae give place to a vigorous growth of *Salicornia* and *Suaeda maritima*; *Aster tripolium* (sea aster) follows this association or indeed may accompany it. On the mud surface, and entwined among these plants, there is often a mat formed of two rootless seaweeds—*Pelvetia canaliculata* and *Bostrychia scorpioides*. There is thus a dense carpet of vegetation, and it is at this stage, when inundations occur at every high water, that accretion goes on most rapidly. If the surface consists of soft mud, *Zostera* species may take the place of *Aster* and *Salicornia*. If the surface is markedly sandy there may be a vigorous growth of *Puccinellia*. At higher levels the sea pink (*Armeria maritima*), the sea arrow grass (*Triglochin maritima*), the sea spurrey (*Spergularia maritima*), and species of sea lavender become prolific. At the highest levels the plantains (*Plantago maritima* or *P. coronopus*), the wormwood (*Artemisia maritima*), and certain species of rush are the commonest plants.

Along the creeks, once they have become fairly well defined, *Halimione portulacoides* (sea purslane) is especially characteristic. This is a low-growing bushy plant with sage-coloured leaves that begins to spread from the creek edges, where drainage is good. It is strong and vigorous and often spreads over large areas of marsh and smothers all other vegetation.

A walk from west to east across the marshes at Scolt Head enables one to compare their heights and relative ages. Those first encountered are almost bare sand flats; then follow those on which only a thin layer of mud has gathered and in which the creek system is embryonic. Next came those in which the mud layer is an inch to a foot or more thick. Where the mud is fairly thick, such marshes are almost completely covered with vegetation and intersected by numerous creeks. Although the creeks originate by the upward and outward growth of marsh, there are places where they lengthen backwards as a result of erosion at the head. If a marsh grows on a gently sloping sand-flat, it may cover the lowest part some time before the upper part. Flooding tides, however, cover the whole, and at the ebb the water is concentrated into the heads of channels and cuts them backwards.

Salt pans are features of nearly all marshes. They are small lakes and of two main types. Some are elongated, and clearly have originated by the interruption of a creek by small dams produced by the growth of vegetation or perhaps by a collapse of the creek bank. The other type is usually round or oval, but sometimes irregular. They are residual hollows; the vegetation spreads over the surface of the marsh in such a way as to enclose parts of it that are without vegetation. As the marsh increases in height the hollows become better defined, and because they are not drained they remain bare. If a small channel is cut to them, so that the water can drain out instead of remaining as a pool after spring tides, they become covered by plants in a year or two and reveal themselves as a very slight depression in the marsh surface.[1]

The marshes in the Dovey are typical of many on the west coast, and their setting in an estuary in a mountain area is a striking contrast to those on the flat coast of Norfolk. The zoning of plants is as noticeable as in Norfolk, but the rarity or even absence of some of the plants on the East Anglian marshes gives them a very different appearance.

The thin layer of mud on the sand, the greater amount of grass marsh, and the scarcity of colour are noteworthy. Since the grass is locally grazed during neap tides, when the sea does not flood the marshes, the surface is often lawn-like. The thin upper layer of finer sediment is held together by roots, and, since it is easily undercut and falls into the creeks, these are unlike those in East Anglia. On the south coast the softness of the mud and the abundance of *Spartina* give the marshes a unique appearance. Readers familiar with Southampton Water and Poole Harbour will realize how rapidly *Spartina* has spread and converted extensive areas of bare, soft mud into green marsh. There are native species of *Spartina*, but *S. townsendii* is a hybrid between the native *S. maritima* and the American *S. alterniflora* and was first noted in Britain in 1869.

Because *S. townsendii* is a remarkably good accretor of mud and silt it is often planted in suitable places to encourage the growth of marsh, either for reclamation purposes or as a factor in sea defence. Unfortunately it has now reached several parts of the Norfolk marshes, where, because of its hybrid vigour, it will, unless checked, spread and bring about great and unwelcome ecological changes.

The vertical thickness of marsh deposits depends primarily on two factors. On a stable coast the thickness is governed by the tidal range. The higher a marsh grows the less it is covered by the tide; its upper limit is governed by the highest tides that cover it. The depth will vary with the slight undulations of the surface on which it has

[1]Some pans have a soft floor of spongy mud. Adequate reasons for this are not known, but the softness may be connected with certain organisms.

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grown. If, however, a coast is sinking, marsh deposits may reach a much greater thickness. The nature of the marsh surface depends a good deal on the rate of sinking. If the upward growth of the marsh equals or exceeds the downward movement of the land or the rise of sea level, the surface appearance will be that with which we are familiar in many of our marshes. If the sinking becomes greater than the growth, the marsh will be swamped and may only appear as a narrow fringe adjacent to the land. If an upward movement of the sea floor occurs, or if there is a fall in sea level, the marsh will soon become dry land.

Since the species of plants growing on a marsh depend in part upon the number of tidal inundations, it follows that if, in a vertical section or bore made in a marsh, traces of plants characteristic of lower zones are found above those belonging to higher ones, a downward movement of the land or rise of sea level may be inferred. Marshes may afford useful means of estimating vertical movements of a coast in unsurveyed lands.

The rate at which marshes grow upwards has been measured in several places. A thin layer of some distinctive material, for example a coloured sand, is spread in patches about a metre square on the marsh and vegetation. If this is done just before a big tide the water will wash the sand off the vegetation, and it is then easy to smooth the patch so that it lies on the marsh surface like the jam on the lower half of a sandwich. All the patches should be marked by a stake driven into the marsh about a metre from them, and they should be carefully levelled. After a period of years they are investigated, either by cutting with a knife, or by pushing a sharp hollow tube into the marsh in such a way as to bring up a small core. The amount of sediment accumulated on the sand can be readily measured. It will vary from place to place. It is usually greatest on low to medium–high marshes densely covered with plants and inundated by most high waters. At higher levels the number of inundations falls off, and the increase in the height of the marsh is slower. At low levels it is usually impossible to use this method, since the sand is washed off bare mud. Table 1 gives some idea of the rates of growth in two different areas.

Many marshes are partly surrounded by dunes. Where this is so, sand may be blown over the marsh, and some may be washed over low dunes in big tides. This helps their upward growth. Occasionally a shingle ridge is breached, and pebbles and other coarse material spread over the marsh surface. Both events illustrate how mixed types of sediment can be produced.

Perhaps the most extensive development of salt marshes in the world is that along the eastern

TABLE I

SCOLT HEAD ISLAND (J. A. Steers)

Missel Marsh is covered by most high tides and the vegetation is mainly *Salicornia*, *S. maritima*, and *Aster tripolium*. *Halimione portulacoides* is beginning to spread from certain creeks. The measurements of sedimentation thickness began in 1935 (September), and the following figures apply to stations at which records were taken in three different years. No. 1 station is at the top of the marsh.

Station No.	1937 (cm)	1947 (cm)	1957 (cm)
2	1·25	8·5	20·0
3	1·25	7·5	17·0
4	1·75	12·5	22·0
9	1·70	9·4	14·0
10	2·50	14·0	23·0
14	1·72	10·0	20·0
16	1·55	11·3	15·0
20	1·72	11·0	19·0
21	1·80	10·5	23·0
22	1·63	10·5	20·0
23	1·60	11·5	17·0
26	1·85	9·8	18·0
30	1·95	12·0	19·0
32	1·60	10·5	17·0
34	1·60	12·5	20·0
35	0·75	10·5	22·0

DOVEY MARSHES (F. J. Richards, *Ann. Bot.*, 48, 225, 1934)

The measurements covered 100 and 54 months respectively, and the two lines crossed all the zones of vegetation.

Line 1, *ca.* 400 ft long.

Association	Accretion (cm in 100 lunar months)	No. of observations
Glycerietum	6·61	8
Transition *Glycerietum-Armerietum*	5·53	7
Armerietum	3·53	30
Transition *Armerietum-Festucetum*	2·00	1
Festucetum	1·75	4
Juncetum	2·03	3

Line 2, *ca.* 250 ft long.

Association	Accretion (cm in 54 lunar months)	No. of observations
Glycerietum	3·67	6
Glycerietum-Armerietum	6·93	2
Armerietum	4·09	15
Festucetum	3·38	6
Festucetum-Juncetum	4·60	1
Juncetum	2·25	1

NOTE. The suffix *-etum* is added to the root of the word to denote the dominant plant in the association.

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FIGURE 1 – *Sand flats: beginning of a thin layer of mud. Algae in rolls. A very early stage in marsh formation. (Figures 1–13 refer to Scolt Head Island, Norfolk.)*

FIGURE 2 – *A later stage: creeks have begun to take definite courses but vegetation is still mainly algal.*

FIGURE 3 – *Vegetation zones on lower Missel Marsh. Sea aster invading* Salicornia *and* S. maritima. *Algae and bare mud at lowest levels.*

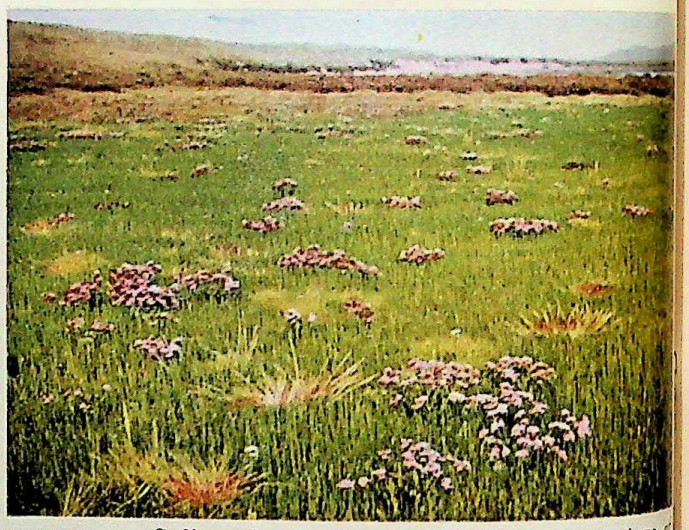

FIGURE 4 – Salicornia *marsh: a marsh in a young stage of development. It is enclosed by shingle ridges and the vegetation (1958) is rapidly changing,* Salicornia *giving place to sea lavender,* Spartina, *etc.*

FIGURE 5 – Suaeda fruticosa *commonly grows at the head of a marsh and the foot of a shingle ridge.*

FIGURE 6 – *Salt pans on Missel Marsh. The rounded form and definite outline are typical.*

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FIGURE 7 – *A creek in Missel Marsh. The banks are lined with* Halimione, *and the mud banks in the creek, which are more frequently covered by the tide, are overgrown with* Salicornia, *etc.*

FIGURE 8 – Spartina *species, including* S. townsendii, *in Norton Creek.* S. townsendii *is spreading all too rapidly in the Norfolk marshes and completely changing their character.*

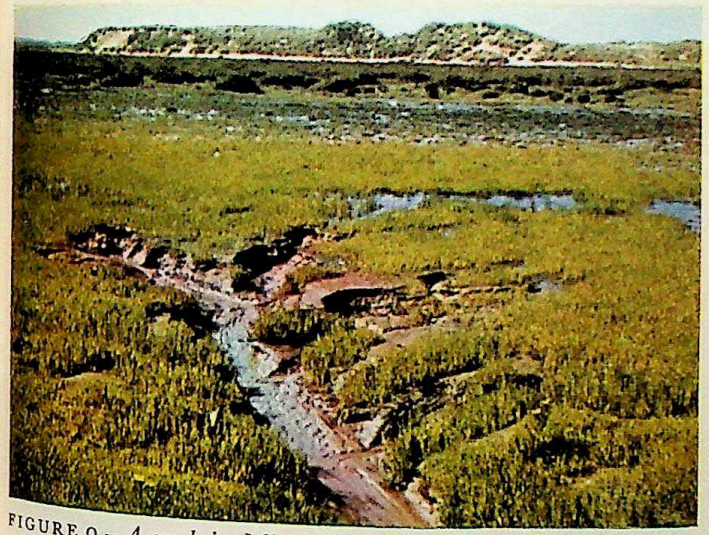

FIGURE 9 – *A creek in Missel Marsh which is lengthening 'backwards' as a result of being cut back by water draining into it as the tide falls and uncovers the marsh or flat above it.*

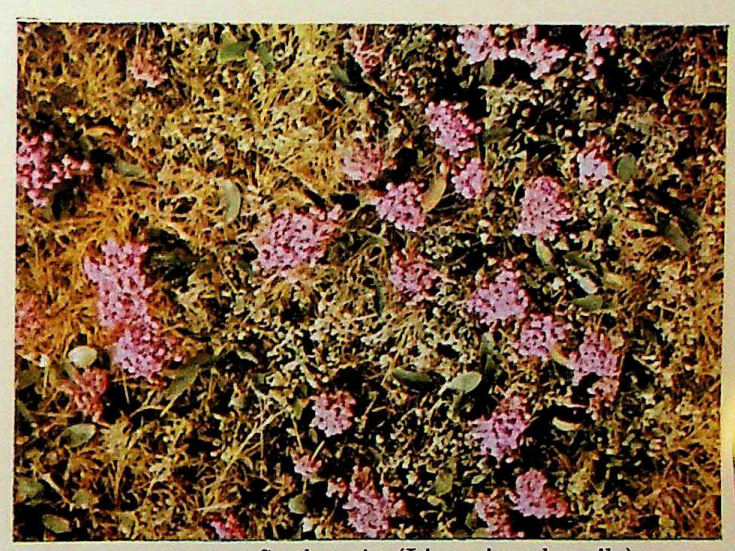

FIGURE 10 – *Sea lavender* (Limonium humile).

FIGURE 11 – *Spiral Marsh: a marsh with a narrow mouth between shingle ridges. The winding of the creek gives it its name.*

FIGURE 12 – *A general view over the Scolt marshes. The view is taken from a point on the highest dunes alongside the sea, looking towards Beach Point and Brancaster Staithe.*

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FIGURE 13 – *Air photograph of a part of Scolt Head Island. The details of the marshes, creeks, pans, vegetation, and the shingle ridges are clearly visible. (Crown copyright reserved. Photograph: J. K. St. Joseph.)*

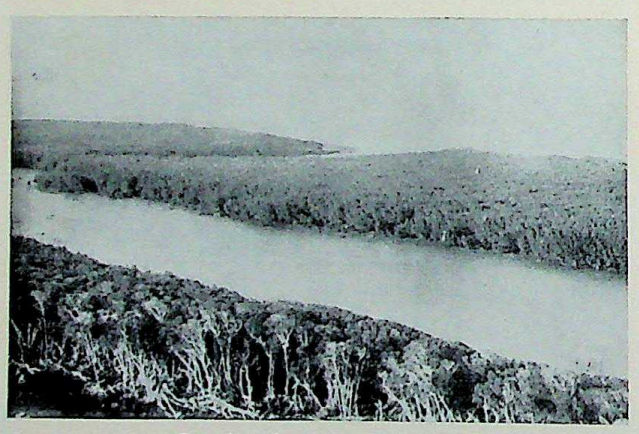

FIGURE 14 – *Detail of mangroves on the north side of Howick Island, Great Barrier Reef.*

FIGURE 15 – *Interior of the mangrove swamp, Newton Island, Great Barrier Reef.*

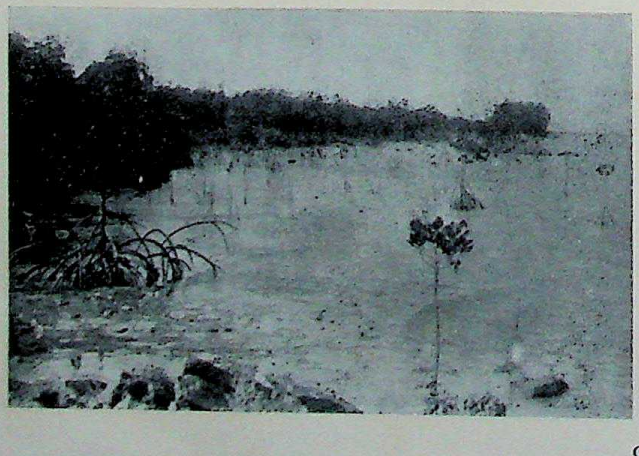

FIGURE 16 (*left*) – *Mangroves at the north-western corner of King Island, Great Barrier Reef.*

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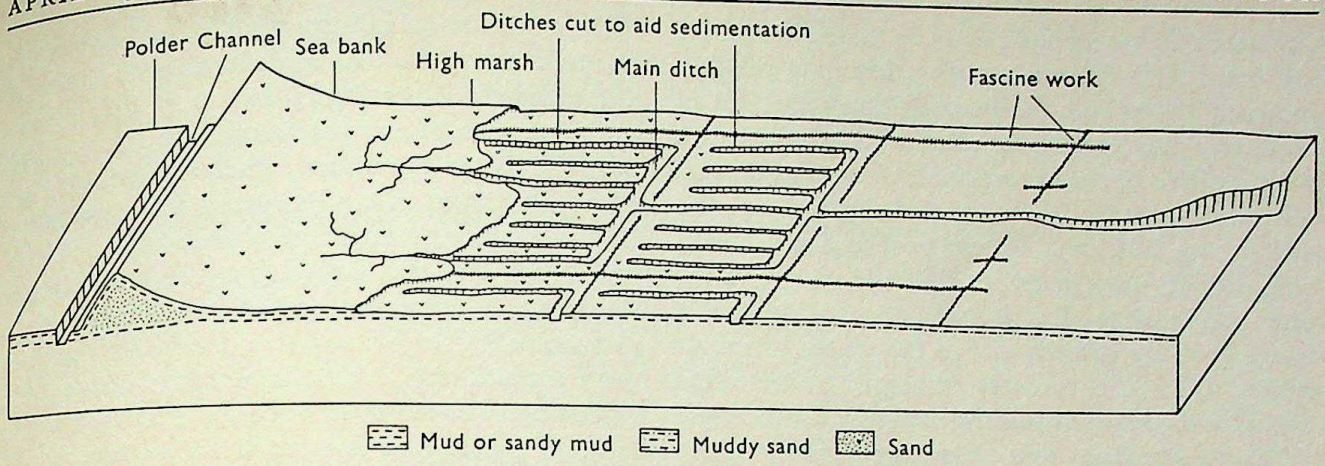

FIGURE 17 – *Schematic arrangement of sedimentary processes. (After F. Verger)*

coast of the United States. From Maine to Florida there is a magnificent development of off-shore bars and beaches on which many seaside towns have been built. Within is a wide marsh area, intersected by many creeks and deep and ramifying inlets. A flight in an aeroplane along this coast is most revealing. The marshes vary from north to south, and three different types have been noted. In New England they consist mainly of bedded grey and brown salt peat with variable amounts of silt, which rests on deep brown or black brackish or freshwater peat. On the surface there are four main vegetation zones—*Juncus* at the top, followed by *Spartina patens*, the broadest zone, then *S. alterniflora*, and finally *Zostera* in a zone almost constantly submerged. Farther north, the Fundy marshes (named after Fundy Bay) are different and built up of a soft red mud or sometimes a hard silt. The surface is often bare, and even when there is vegetation it is rather sparse. A great deal of land has been reclaimed. The plants are similar to those in New England except that the *Zostera* zone is missing, possibly because of the strong tides, the range of which exceeds fifty feet in places. The mud is fairly firm, and derived from the soft sandstones and shales surrounding the bay. In the Great Tantramar marsh, eighty feet of mud overlie two feet of freshwater peat—a clear indication of subsidence.

South of New England, and extending into Florida, is the third type—the coastal plain marshes. They are characterized by *S. alterniflora*. The average thickness of the deposits is ten to twenty feet, and consist of a bluish-grey silt or clay, with little peat. It has been suggested that the softer rocks adjacent to the coast south of New Jersey afforded abundant silt for the formation of the coastal plain type, whereas north of New Jersey the rocks are more resistant, and the stream

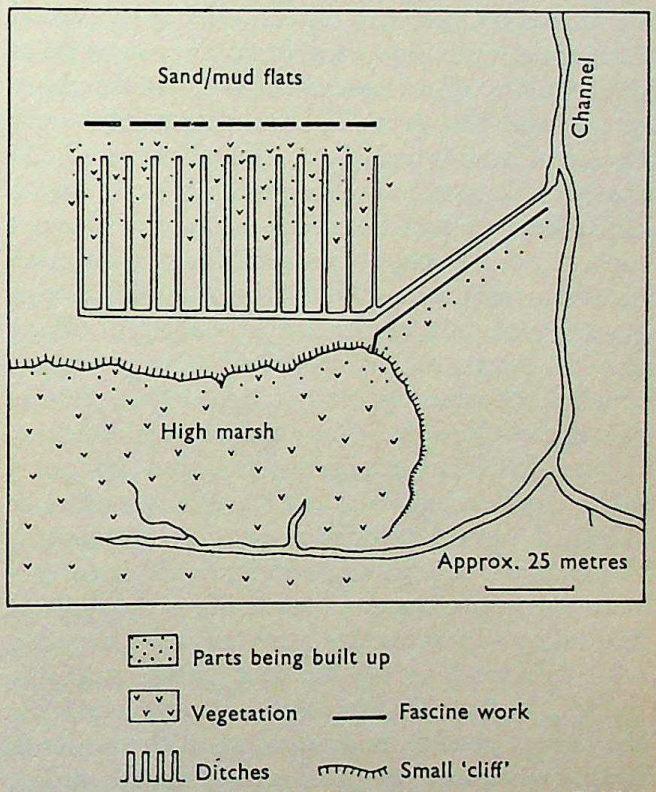

FIGURE 18 – *Simplified sedimentation scheme at Rejsby, Denmark. (After F. Verger)*

loads are dropped in lake and swamp. Thus the mineral sediment in the marshes is subordinate to the remains of vegetation, especially grasses.

In the tropics the mangrove takes the place of the low-growing plants of temperate latitudes. Hundreds of miles of coastline, especially in river mouths, are lined by mangroves (figures 14–16). They are typical of muddy coasts where there is some shelter and where the land is growing seawards. They are also found on coral and other reefs at some distance from land. Wherever they thrive they lead to the upward and outward growth of land, partly by trapping sediment

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carried in the water and partly by their own decay. On coral reefs there is often an intimate relation between them and the stabilization of ridges of coral shingle. On many coral islands within the main barrier of the Queensland coast, and also on several cays around Jamaica and other places, the mangroves take root on the reef and grow to a height of 30–40 ft or more. The islands are in the open sea, and the first impression of them is of a forest growing directly out of the water. In their spread over the reef the mangroves are often accompanied by marine angiosperms, for example *Thalassia testudinum* and *Cymodocea manatorum*, and sometimes the grass *Spartina alterniflora*.

The word 'mangrove' is used in a double sense, for an ecological group of plants living in tropical tidal areas, and also for communities composed of these species. The trees and shrubs, like the plants of salt marshes, grow in zones according to the degree of tidal inundation. The pioneer is *Rhizophora mangle* (common mangrove), which forms a dense forest 30 ft tall or more. *Avicennia* follows at rather higher levels, but on coral reefs it may often be found seawards of the *Rhizophora* because it grows on slightly higher ridges of shingle. Along tropical coasts the *Avicennia* association grows best on land not regularly covered by the tide. Within this again there may be another species—*Conocarpus*. It is frequently accompanied by many other trees and grasses, but since it can often be shown to have developed on land first formed by the mangroves, it should be mentioned here.

A mangrove swamp shows how the growth and decay of trees and other vegetation, together with the trapping of silt, mud, sand, and even shingle, lead to the formation of new land. But the dismal glades, the equivalent of the creeks in salt marshes, and the dull green of the vegetation, to say nothing of the swarms of mosquitoes and other insects that often live in the mangroves, make them far less attractive than a British salt marsh. Yet, in both, new land is in process of formation, and if one wishes to reclaim the swamps and marshes it is a comparatively easy matter.

Reclamation of salt marshes should not be attempted too soon. A considerable thickness of fine sediment is necessary before a wall is built round an area of natural marsh. In many places, particularly in Denmark and north-west Germany, the marshes are prepared for reclamation by the digging or mechanical excavation of shallow dykes, and the throwing up of low ridges of the material excavated, so as to encourage sedimentation (figures 17 and 18). In Britain reclamations around the Wash have added more than 45 000 acres to our area since the Roman occupation. A journey to the Wash shows that as one approaches the coast the level of the land gradually rises. The same feature is seen all round the coasts of Britain where a wall divides reclaimed and open marsh. The former has settled and drained, whereas the latter is still accreting. If reclamation is carried out too quickly, the depth of fertile silt is insufficient. Sometimes reclamation is valueless. Large areas of Morecambe Bay were enclosed, but since they consisted of almost pure sand they were useless and were abandoned.

Salt marshes are of great interest to the physiographer because there are few places where changes go on so quickly and where they can be measured so effectively. Additionally their intimate relation with shingle ridges and sand dunes greatly increases their value as fields of study. To the ecologist they are significant because of the interrelation of the plant cover to substratum and tidal flooding. To the geologist they often present interesting illustrations of the ways in which very coarse and fine sediments can originate. To the coastal engineer the growth of a marsh suggests a protection for a stretch of coast, and the rapid growth of *Spartina* is a potent factor in reclamation. The study of marshes throws much light on vertical movements of the coast. They are also often places of great beauty. The ever-changing tidal conditions, the setting whether in a mountain-girt estuary or on an open coast, and the colours of the flowering plants—sea pink, sea lavenders, and sea aster—at different times of the year are unforgettable.

BIBLIOGRAPHY

TANSLEY, A. G. 'The British Islands and their Vegetation.' Cambridge University Press, London. 1939.

STEERS, J. A. 'The Coastline of England and Wales'. Cambridge University Press, London. 1948.

Ibid. (Editor). 'Scolt Head Island' (second edition). Heffer, Cambridge. 1959.

CHAPMAN, V. J. *J. Ecol.*, **26**, 144, 1938; **27**, 160, 1939.

JOHNSON, D. W. 'New England-Acadian Shoreline'. John Wiley & Sons Inc., New York. 1925.

RICHARDS, P. W. 'The Tropical Rain Forest'. Cambridge University Press, London. 1952.

'The Structure and Ecology of Low Isles and Other Reefs'. *Sci. Rep. Gt. Barrier Reef Exped.*, III, 1931.

STEERS, J. A. *Geogr. J.*, **74**, 232, 1929; **89**, 1, 1937.

VERGER, F. *Ann. Géogr.*, **65**, 270, 1956.

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X-ray fluorescence spectroscopy in chemical analysis

E. T. HALL

The theory of X-ray spectroscopy has long been understood, but the main progress in its application has taken place since 1945, stimulated by new apparatus and electronic circuits then becoming available. This apparatus, together with some of the results obtained by its use—which include the discovery of the nature of the Piltdown skull—are discussed here.

H. G-J. Moseley, in 1914, established the basic principles of X-ray spectroscopy, and later workers discussed its application to chemical analysis [1–4]. Five of the elements then missing in the Periodic Table (hafnium, technetium, rhenium, promethium, and francium) were discovered by this technique, but most of the progress in the field has been made since 1945 [5, 6]. This started with the development of new apparatus, such as low-energy Geiger counters and small high-power X-ray tubes, and has progressed to the commercial manufacture of X-ray fluorescence spectrometers.

BASIC THEORY

Early experiments relied on primary excitation of the specimen under investigation. In this technique the sample is made the target, or is smeared on the massive pure-metal target, of the X-ray tube. Electrons from the hot filament strike this target, causing it to emit X-rays which have an energy distribution similar to that shown in figure 1. The sharp peaks shown there are characteristic of the elements in the target, and these are superimposed on a 'white' continuum. The position of these peaks in the spectrum is the basis of qualitative X-ray analysis, while the height above the continuum will, in principle, indicate the amount of the target element present. The mechanism by which these excitation lines appear can be explained on the simple Bohr-Kossel model of the atom, in which the electrons surrounding the nucleus are distributed in shells designated as K, L, M, etc. Removal of an innermost (K) electron requires the most energy, and only when the bombarding electrons exceed a certain 'critical excitation voltage' will one of these electrons be ejected. Its place is immediately filled by an electron from an outer shell, and a K-series X-ray is released. L-series X-rays will be evolved at lower excitation levels when M-shell electrons replace those ejected from the L shell. Even though this is a much simplified picture, it is important to note that the number of possible lines for any one element are very much less than in the optical region of the spectrum. In practical spectrometry we are concerned with not more than five lines for any one element—the others can be neglected because of experimental limitations. The small number of measurable lines is a great advantage in most instances, since interference becomes less likely.

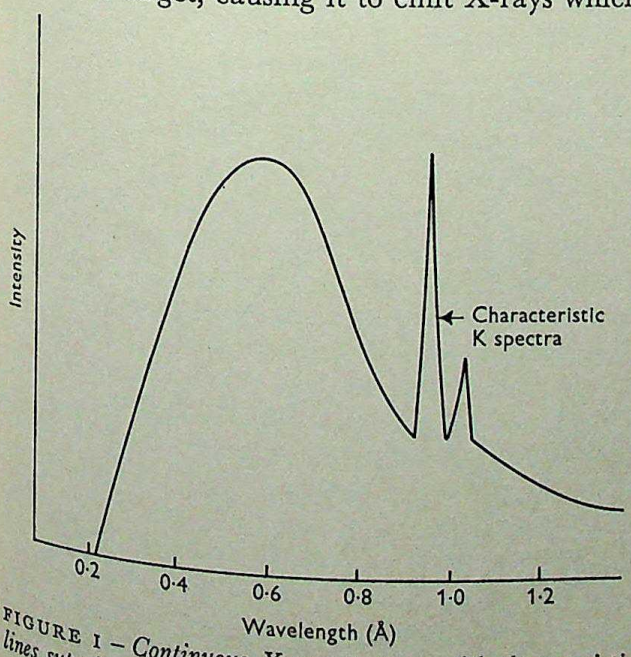

FIGURE 1 – *Continuous X-ray spectrum with characteristic lines superimposed.*

There are serious disadvantages in such 'primary X-ray' spectrometry, where the sample is inside the X-ray tube, on account of the difficulties associated with tubes that can be opened, thermal decomposition, and selective volatilization of the sample. In order to avoid these drawbacks we can resort to the phenomenon of 'secondary X-rays' or X-ray fluorescence. In this method the sample is outside the X-ray tube and it is

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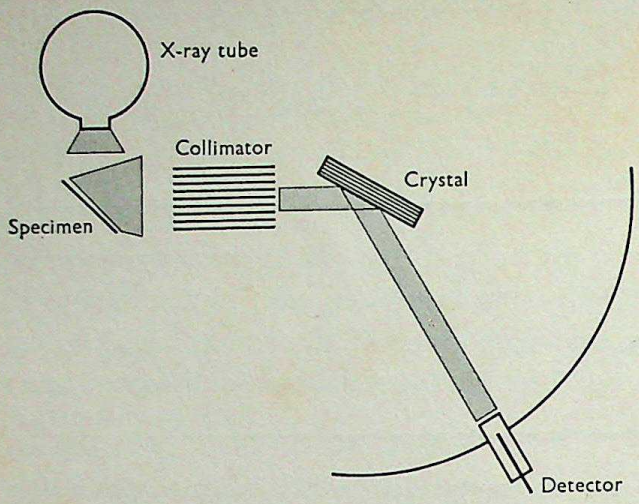

FIGURE 2 – *Flat-crystal spectrometer.*

irradiated with the primary 'white' radiation, which causes it to fluoresce with X-rays whose wavelengths are the same as those superimposed on the continuum discussed above; no continuum is excited in this way. A high proportion of the incident 'white' radiation is scattered, and the resultant characteristic peaks are very much reduced compared with those generated by electron bombardment. Nevertheless, ample intensity for accurate and quick quantitative analysis in many applications can be obtained by using the new high-intensity tubes and bombarding a large area of specimen.

Two main types of spectrometer are in use for resolving fluorescent radiation into its component wavelengths. Figure 2 shows the 'flat crystal' type. Here the secondary rays are collimated by long bundles of narrow thin-walled tubing or by parallel blades of thin sheet. The collimated beam strikes a large crystal of known grating constant, and when this crystal obeys the Bragg condition of reflection for a certain wavelength, a proportion of the rays with this wavelength will be reflected into the detector.

Under all other conditions, radiation of this wavelength will be scattered. The detector is geared to the crystal so that it is always in a position to receive the reflected rays. By slowly rotating the crystal and detector we can investigate the entire spectrum of the specimen.

This is an extremely simple type of spectrometer but suffers from attenuation of the beam incident on the crystal because of the collimation imposed by the slit system. Of course, the greater the resolution required the greater the collimation must be.

To increase this 'useful' intensity we can use a bent crystal, analogous to the concave reflection grating of the optical spectrometer. Figure 3 illustrates the principle. A point source of fluorescent rays irradiates an area of crystal that has been bent with its crystal planes on the circumference of a circle of radius R and has been ground with an inner surface of radius $R/2$. This inner surface is on a circle which passes through the point source. Radiation of wavelength λ striking the crystal planes at an angle θ will be focused again on the same circle as the source. Although this type of spectrometer gives a much enhanced reflection into the detector, the geometry of the system requires a more complicated mechanism than does the simple plane spectrometer. Moreover, since a point source is 'looked at' rather than an area of perhaps three square centimetres, a valuable integration factor is removed. Optical spectrographers will appreciate this difficulty, since sampling errors are a continual worry where only a small area is involved in the spark.

SCOPE AND LIMITATIONS OF THE METHOD

The energy of characteristic secondary X-rays varies with the atomic number of the element. If this energy is too small, the radiation will be unable to penetrate the air between the specimen and detector. This is so with elements of lower atomic weight than titanium. However, a vacuum or helium-filled spectrometer can be used for the elements between magnesium and titanium. For elements below magnesium even this technique will be unsuccessful, as the detector window will be too absorbent.

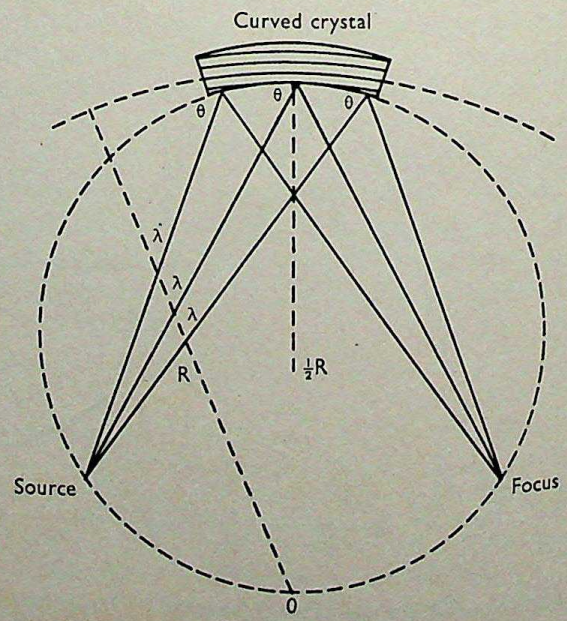

FIGURE 3 – *Curved-crystal spectrometer.*

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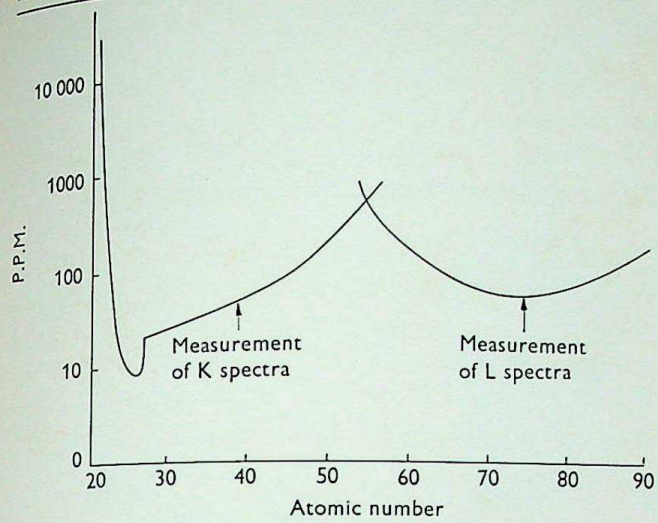

FIGURE 4 – *Curve showing sensitivity against atomic number.*

The sensitivity of the method for any particular element will depend on many factors, such as spectral resolution desired, reflectivity of crystal, type of detector used, and the energy of the primary X-ray beam. Moreover the main element of the target, when we are looking for a trace impurity, will have a large effect on the sensitivity. These variables make it difficult to compare the sensitivity of the method with that of other techniques. However, to give some idea, figure 4 shows the sensitivity of one particular instrument measuring all possible elements in an iron matrix, using an air-path spectrometer.

COMPARISON WITH OPTICAL SPECTROSCOPY

In order to assess the potentialities of this technique it is convenient to make comparisons with the optical spectrograph. In the writer's view the two techniques should be thought of as complementary—the time certainly has not arrived where the analytical chemist and optical spectrographer will be superseded.

The X-ray method is particularly valuable for elements above atomic number 20 present in concentrations ranging from 0·1 per cent to 100 per cent. The optical spectrometer, on the other hand, deals best with trace amounts from 0·0005 per cent to 5 per cent of most elements in the Periodic Table. The extension of the X-ray method to the elements of atomic number 11–20 presents difficulties which, although not insuperable, nevertheless render it inconvenient. However, emphasis should be given to the fact that concentrations above 10 per cent cannot generally be tackled by optical methods, whereas it is just such concentrations that are most favoured by X-ray spectrometry.

There is no doubt that as a non-routine laboratory tool X-ray methods are faster than optical ones, mainly because the photographic step is eliminated. They both require standardization techniques to obtain reliable results. However, direct-reading optical spectrometers, which use photomultiplier methods for obtaining quantitative results, are inherently as rapid as similar instruments that are just beginning to appear in the X-ray field. The non-destructive nature of X-rays as compared with the optical spark or arc may be important if one wants to examine either valuable specimens or finished manufactured goods.

The spectral line structure is infinitely simpler in the X-ray region. In fact there are some problems which can be solved only by the X-ray method because of line interference in the optical region; tantalum, niobium, and rare earth mixtures are notable examples.

In quantitative work the accuracy attainable by X-ray methods should be greater than that of optical emission methods. In X-ray spectrometry we are counting quanta arriving in a random fashion, and in order to increase accuracy all we have to do is to increase the total number of quanta recorded, that is, increase the time of counting. This means in practice that in order to get a 1 per cent accuracy of content, as little as one second devoted to a major constituent may suffice, whereas a minute per element may be required when estimating minor constituents. These times are remarkable when compared with the hours required for many conventional chemical analyses.

In both methods the state of chemical combination is immaterial, although standardization is best carried out under identical conditions. However, the author has found that good approximate results can be obtained using solutions in place of solids when this is possible, and standard solutions are relatively easy to prepare. In optical spectrometry, molecules not atoms are involved in excitation. The reverse is the case in the X-ray region. For this reason chemical combination is all-important in the former case, and results obtained with mixtures of salts or solutions may bear no relation to those obtained with the pure elements.

Optical equipment is now produced on a fairly large scale by several firms at a reasonable price. X-ray fluorescence equipment, on the other hand, is mainly supplied as an attachment to X-ray diffraction apparatus, which is not so satisfactory

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as an instrument specifically designed for the job. Moreover, diffraction equipment involves a scanning technique, whereas in fluorescence we require measurements only on the top of known peaks. However, as has been stated above, direct-reading machines are just beginning to appear, and the prices of these are comparable with those of direct-reading optical equipment.

FUTURE DEVELOPMENT

There are some interesting possibilities for the development of X-ray fluorescence analysis. Perhaps the most obvious improvement would be an extension of the method to elements of lower atomic number. This extension by the use of a vacuum spectrometer is an engineering problem which is now being solved. With suitable crystals and detectors, elements between aluminium and titanium will be estimated with the same ease as elements of greater atomic weight. The development of electron multipliers for elements lighter than aluminium is proceeding apace, and we can look forward in the next few years to having the whole Periodic Table covered by X-ray analysis.

Several workers are experimenting with non-dispersive X-ray spectrometry. Here, the use of pulse-height discrimination in the detector circuit may achieve the same result as spectral resolution by means of diffraction by a crystal. This would have two advantages—it would dispense with mechanical moving parts and also improve the counting speeds attainable, and hence the speed of analysis. There are, however, considerable practical difficulties.

The use of radioisotopes, instead of an X-ray tube and generator, as the exciting source of secondary X-rays from the specimen is an attractive possibility. Although the secondary yield will be considerably below that produced by a high-power X-ray source, the combination of stability, the avoidance of a bulky high-voltage generator, and the monochromatic nature of the exciting beam could offset this disadvantage in many applications.

Perhaps the most important development of X-ray spectroscopy during the last few years is that using the various electron microprobe techniques originating in work by R. Castaing [7–9]. In this method a beam of electrons as little as 1 micron in diameter is focused on the specimen, and the resulting characteristic X-rays are detected by a bent-crystal spectrometer. In this way the microstructure of metals and other materials can be studied in detail.

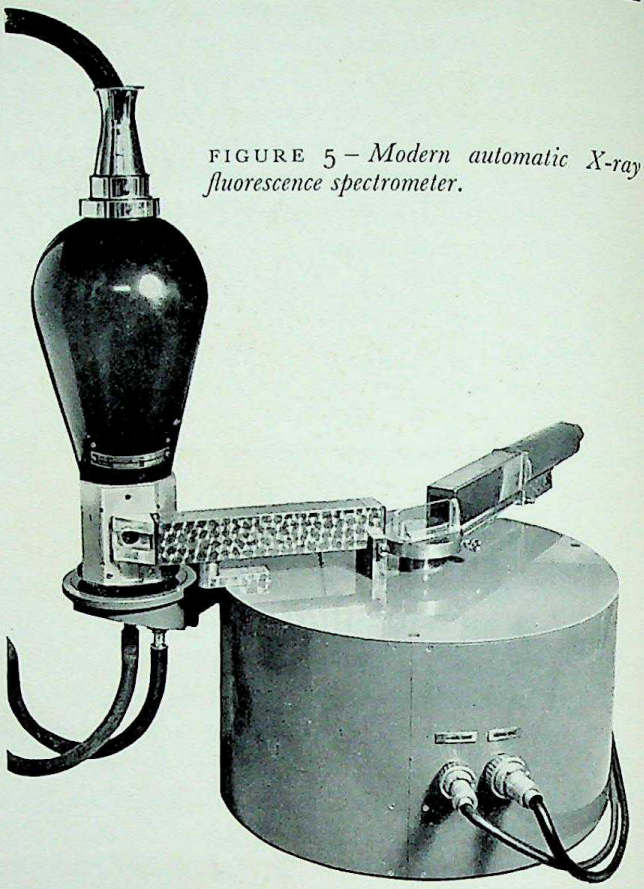

FIGURE 5 – *Modern automatic X-ray fluorescence spectrometer.*

SOME APPLICATIONS

X-ray fluorescence analysis is particularly suited to archaeological specimens and other material where it is important that no damage is done to the specimen. Routine analyses of this kind have been proceeding for some years in Oxford at the Research Laboratory for Archaeology and the History of Art. One of the first problems presented was the analysis of the Piltdown skull fragments and flints. The question was whether the bones and flints had been artificially stained by an inorganic pigment in an attempt to imitate the ferruginous colour imparted to buried objects in the locality in which they were reported to have been found. It so happened that this was a perfect problem for the X-ray spectrometer, which in addition fulfilled the essential requirement of being non-destructive. The stain (if there was one) would be located on the surface of the specimen and thus, although present only in milligram quantities, would give a large amount of fluorescence compared with that produced by a similar quantity spread throughout the whole specimen. In fact, the skull fragments did give a significant chromium peak, as also did the flints, showing that the chemical was mainly on the surface. No comparable genuine fossils gave a

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similar peak. The conclusion finally reached was that the forger simulated true buried objects by boiling modern ape bones in potassium dichromate solution. The author has tried this and has obtained very similar results—both as to appearance and as to the readings obtained by X-ray fluorescence.

The fact that the surface of a specimen will contribute much more to the analysis than underlying layers can be an advantage or a disadvantage, according to the circumstances. In the tinplate industry, X-ray fluorescence of the iron can be used to measure the thickness of the tin layer above it. The primary X-rays striking the sheet of metal will be attenuated, as also will the secondary radiation from the iron on its way to the detector.

Conversely, in the archaeological field, when such objects as coins that have been buried for centuries are analysed one may find that the apparent analysis differs considerably from the average value found by such methods as γ-ray spectrometry. This is due to surface enrichment of one constituent at the expense of another. Values obtained by X-ray fluorescence must therefore be treated with reserve. Research now in progress at Oxford will try to elucidate this problem of surface enrichment. It may be due to leaching of the more soluble constituents from the coin by solution in the soil, or to a very gradual migration of one constituent towards the surface. If the latter is the case, we might have an interesting method of dating ancient metallic objects. The problem will be tackled by taking cross-sections of the coins, analysing by the X-ray microprobe technique across the thickness of the metal, investigating how the composition varies with depth, and then comparing these 'composition contours' with the date of manufacture.

The analysis of glass and ceramics by wet methods presents an awkward problem to inorganic chemists. X-rays are especially useful in this field, since no solution of the specimen is necessary. Although many of the constituent elements occur in the 'vacuum spectrometer' region, this problem, as has been mentioned above, will be resolved when suitable equipment is available. Two examples, in the archaeological field, will suffice. The blue pigment in Chinese blue-and-white porcelain was made during early Ming times from imported cobalt ore which happened to be free from manganese. From the late Ming period onward, indigenous pigment containing a considerable percentage of manganese was used. Since eighteenth-century porcelain is hard to distinguish from early pieces, the presence of manganese found by non-destructive X-ray analysis can help in identification. Again, the presence of barium in large amounts in early glass is indicative of a Chinese origin, since Mediterranean glass appears to be free from that element.

Applications in the industrial field at the moment tend to be directed towards analysing alloys of high percentage composition or mixtures difficult to analyse by other means. Typical of the former are the estimations of copper and zinc in brass, of copper, zinc, and lead in powdered ore concentrates, and analysis of the Nimonic alloys. In the latter category the analysis of mixtures of the rare earths, of niobium and tantalum, of hafnium and zirconium, and of the platinum metals are cases where X-ray spectrometry is very superior to other methods of analysis.

The possibilities of the method in the analysis of solutions of very low concentration are little appreciated. For instance, as little as 10^{-8} g of many elements in solution, applied to a filter paper, will give an adequate response for purposes of identification, and in many instances less than one part per million in solution can be detected. Again, trace concentrations of the order of a few parts per million can be detected in light alloys, such as those of aluminium and beryllium, as can microgram quantities of uranium. Thus there are very many present uses of X-ray fluorescence, and no doubt in the near future we shall see a startling advance in the general application of this rapidly developing technique.

REFERENCES

[1] VON HEVESY, G. 'Chemical Analysis by X-rays and its Application'. McGraw-Hill Book Co. Inc., New York. 1932.
[2] LABY, T. H., EDDY, C. E., and TURNER, A. H. *Proc. roy. Soc. A*, **135**, 637, 1932.
[3] CLARK, G. L. 'Applied X-rays'. McGraw-Hill Book Co. Inc., New York. 1940.
[4] FONDA, G. R. and COLLINS, G. B. *J. Amer. chem. Soc.*, **54**, 115, 1932.
[5] FRIEDMAN, H. and BIRKS, L. S. *Rev. sci. Instr.*, **19**, 323, 1948.
[6] BIRKS, L. S. *Ibid.*, **22**, 891, 1951.
[7] CASTAING, R. and DESCAMPS, J. *J. Phys. Rad.*, **16**, 304, 1955.
[8] COSSLETT, V. E., DUNCOMB, P., LONG, J. V. P., and NIXON, W. C. 6th Annual X-ray Conference, Denver. 1957.
[9] BIRKS, L. S. and BROOKS, E. J. *Loc. cit.*

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The International Council of Scientific Unions

SIR HAROLD SPENCER JONES

The International Geophysical Year ended on 31st December 1958. This was the largest scheme of international co-operation in science that has ever been planned, and was organized by a special committee of the International Council of Scientific Unions. It was, however, only one of the achievements of the Council, and the origins, the activities, and some of the future programme of this non-political international scientific council are described in this article. The author was the Secretary-General of the Council from 1956 to 1958.

International co-operation in science was effected before the first world war through a heterogeneous collection of associations, each concerned with a very restricted domain of the various scientific disciplines. Most of these bodies had been established during the second half of the nineteenth century. Some of them were organized under inter-governmental diplomatic conventions, but many others were directly under German auspices and during the war became largely inactive. At a conference in London in October 1918 it was resolved that it was desirable that the nations at war with the Central Powers should withdraw from the existing conventions relating to international scientific associations as soon as circumstances permitted and that new associations, deemed to be useful to the progress of science and its applications, should be established without delay by the Allies, with the eventual co-operation of neutral nations.

The war ended in the following month, and the American scientist George Ellery Hale proposed that an international research council should be formed to establish new associations for co-ordinating international efforts in the different branches of science. On the joint initiative of the *Académie des Sciences*, Paris, the Royal Society of London, and the National Academy of Sciences, Washington, the International Research Council was founded in 1919. Its primary objects were to co-ordinate international efforts in the different branches of science and its applications, and to initiate the formation of international associations and unions deemed to be useful to the progress of science.

The Statutes of Scientific Unions formed under the aegis of the Council required the approval of the Council, and only allied and neutral nations were admitted to the International Research Council and the Unions. In 1919 the International Unions of Astronomy, of Geodesy and Geophysics, and of Chemistry were formed, and were followed in succeeding years by the International Unions of Scientific Radio, of Pure and Applied Physics, of Biological Sciences, and of Geography.

By 1925 the feeling had become rather general that international collaboration in science could not be fully effective while the Central Powers were excluded from membership of the Council and of the Scientific Unions. At the General Assembly of the IRC in that year a proposal was made by the Netherlands delegation that the Statutes should be modified to permit the Central Powers to be eligible for admission. This proposal was strongly supported by the delegations of Denmark, Sweden, the United Kingdom, and the United States, but did not receive a sufficient majority of votes for acceptance. At the same time the Unions were feeling that their activities and usefulness were being hampered by the restrictions placed upon them under the existing Statutes of the IRC.

As the Convention under which the International Council was constituted would have lapsed on 31st December 1931 unless previously renewed, the Royal Society of London proposed, at the General Assembly of the IRC in 1928, that a committee should be appointed to consider what changes, if any, should be introduced in the Statutes of the IRC and of its Unions, to take effect on the expiration of the Convention. The proposal was unanimously adopted and, as a result of the report of the committee, the International Research Council was reconstituted in 1931 as the International Council of Scientific Unions (ICSU), whose main purposes, according to the statutes then adopted, were to co-ordinate the national adhering organizations and also the various International Unions, and to direct scientific activity in

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subjects for which there was no existing international association. At the same time each of the Unions was given complete autonomy in the management of its own affairs.

At the General Assembly of the ICSU in Copenhagen in 1949 various modifications to the Statutes were discussed, and at the General Assembly in Amsterdam in 1952 the present Statutes were adopted. The first of the Statutes states that the ICSU has two chief objects:

(*a*) to co-ordinate and facilitate the activities of the International Scientific Unions in the field of the Natural Sciences;

(*b*) to act as a co-ordinating centre for the National Organizations adhering to the Council.

Further objects of the Council are:

(*a*) to encourage international scientific activity in subjects which do not fall within the purview of any existing international organizations;

(*b*) to enter, through the National Adhering Organizations, into relations with the Governments of the countries adhering to the Council in order to promote scientific investigation in those countries;

(*c*) to maintain relations with the United Nations and its specialized agencies;

(*d*) to make such contacts and mutual arrangements as are deemed necessary with other International Councils or Unions, where common interests exist in the field of the Natural Sciences covered by the Council.

The Council has two categories of membership, national and scientific. National members adhere to the Council through a national organization, which may be either its principal scientific academy, or its national research council, or any other institution or association of institutions; or, failing these, the government. The scientific members of the Council are the Unions whose admission has been granted by the General Assembly. These Unions are now thirteen in number. In 1947 International Unions for Crystallography, and for Theoretical and Applied Mechanics, were accepted as scientific members, followed in 1952, by the International Union of Mathematics, in 1955, by the International Unions for Physiological Sciences and for Biochemistry, and in 1956, by the International Union for the History and Philosophy of Science.

The ICSU is administered by the General Assembly, which normally meets at three-yearly intervals, the Bureau, and the Executive Board. The General Assembly, to which the Bureau and the Executive Board are responsible, consists of the representatives of the national members and of the scientific members and elects the members of the Bureau. The Bureau is responsible for the general administration and meets at least once a year. The Executive Board consists of the members of the Bureau and of representatives of the scientific members and normally meets once each year.

The structure of the ICSU with its dual membership, national and scientific, which has developed from experience through the years in the organization of international co-operation in science, is of special interest. The ICSU is an international federation of Scientific Unions, each of which is completely autonomous in the management of its own affairs, and can admit national members, irrespective of whether they are members of the ICSU or not. The national members of the ICSU, at present 45 in number, help to guide the general policy of the Council through their representation at the General Assemblies of the ICSU, and have direct contact with the Unions through the National Committees. Each of the Unions has a National Committee in each of the countries that adheres to it. These National Committees may be formed under the national academy or research council which adheres to the ICSU, for example, in Great Britain under the Royal Society of London, in the United States under the National Academy of Sciences, or may be formed under a specialized scientific society as, for instance, in the International Astronomical Union, the National Committee for Astronomy for Germany is formed under the *Astronomische Gesellschaft*.

Unesco was formed in 1946 as one of the specialized Agencies of the United Nations. While ICSU is a non-governmental organization, Unesco is an inter-governmental organization, whose adherents are its member states. Unesco and ICSU have a number of overlapping interests and activities in the field of the natural sciences. A formal agreement was therefore drawn up between the two bodies in 1946, and this has been renewed yearly. Unesco recognizes that the International Scientific Unions provide a natural and appropriate means for the international organization of science, that the ICSU is the proper organism for representing them and co-ordinating their activities, and that the objects of the ICSU are in harmony with those of Unesco. The activities of the ICSU are in a field which is of interest to a large section of the programme of Unesco, so that the ICSU is in a position to provide an

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important contribution towards the realization of the programme and objectives of Unesco.

Under this agreement Unesco provides an annual subvention to the ICSU to assist in the co-ordination of the activities of its members and to assist the financing of international scientific projects which are in accordance with the objectives of Unesco. Unesco is represented at the meetings of the Executive Board and General Assembly of the ICSU. The ICSU in return offers expert advice and counsel when called upon by Unesco. A provisional allocation of the Unesco subvention is made annually by a small committee set up by the ICSU for this purpose; each Union is then informed of this provisional allocation and may make suggestions for modifications or increases in the grants proposed. The allocation between ICSU and the Unions is further considered by the Bureau of ICSU and submitted to the Executive Board for approval or modification and for adoption.

There are various fields of interest shared between two or more Unions. In order to deal with these, Joint Commissions between two or more Unions have been formed where the need has been felt. These at present are five in number, namely the Joint Commissions on the Ionosphere, on Radio Meteorology, on Solar and Terrestrial Relationships, on Spectroscopy, and on Applied Radioactivity. The Joint Commission on the Ionosphere has representatives of the Unions of Radio Science, Astronomy, Geodesy and Geophysics, and Pure and Applied Physics. The Joint Commission on Radio Meteorology has representatives of the Unions of Radio Science, of Geodesy and Geophysics, and of Pure and Applied Physics. The Joint Commission on Solar and Terrestrial Relationships has representatives of the Unions of Astronomy, of Radio Science, and of Geodesy and Geophysics. The Joint Commission on Spectroscopy has representatives of the Unions of Pure and Applied Physics and of Astronomy. The Joint Commission on Radioactivity has representatives of the Unions of Chemistry, of Physics, of Biological Sciences, of Geodesy and Geophysics, of Biochemistry, and of Physiology. It may be mentioned that the first formal proposal for a third International Polar Year, not restricted to the Polar regions, came from the Brussels meeting of the Joint Commission on the Ionosphere in 1950.

Another activity of ICSU has been the formation of Special Committees to organize specific programmes of research in which international co-operation is necessary. There are at present three of these Special Committees, namely the Special Committee for the International Geophysical Year 1957–58, formed in 1953; the Special Committee on Oceanic Research, formed in 1957; and the Special Committee on Antarctic Research, formed in 1958.

The way in which the enterprise of the IGY was organized is of interest. The Special Committee, through a working group in each of the disciplines involved, first laid down the broad lines of the global problems for whose solution observations in all parts of the world were required. The National members of the ICSU and, also, countries not yet adhering to it, were asked to form National Committees to consider to what extent each country could contribute to the achievement of the objectives. From the National Reports and from subsequent meetings, negotiations, and proposals, the world-wide programme of simultaneous geophysical observations for 1957–58 was evolved. An Advisory Committee for the IGY, on which each participating country was represented, was formed to meet in conjunction with the Special Committee.

The enterprise of the IGY has proved to be by far the largest scheme of international co-operation in science that has ever been planned. Sixty-seven countries have co-operated in the programme, in which there have been more than 2000 observing stations well distributed over the whole earth. A special feature of the IGY has been the extensive use of instrumented rockets to obtain information about the upper levels of the atmosphere beyond those that can be reached by instrumented balloons, followed by the successful launching of instrumented earth satellites. The proposal that the launching of such satellites should be attempted originated with the Joint Commission on the Ionosphere and was supported by the Special Committee for the IGY.

Arrangements have been made for the storage of the vast mass of data obtained during the eighteen months of the observational programme at three World Data Centres, from which data can be obtained by scientific investigators who wish to use them.

Another special feature of the IGY programme has been the large programme of research in the Antarctic, a great and relatively unknown continent, which is of special significance to geophysics in many directions. During the IGY, 57 stations in the Antarctic were operated by 12 nations. As there was a widespread feeling that Antarctic research should not come to an end with the termination of the IGY, the ICSU has appointed a

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Special Committee on Antarctic Research to organize the continuation of research in the Antarctic following the IGY, though necessarily on a somewhat reduced scale.

The observational programme of the IGY terminated on 31st December 1958, and consequent upon this, two further measures have been taken by the ICSU. In the first place there was a general feeling that the observational and data-collecting activities in the geophysical and related sciences should be continued after the end of the IGY. It has therefore been agreed that observations should be continued throughout 1959 at such a level and in such fields as may be determined by each National Committee. This extension of the IGY programme has been designated the International Geophysical Co-operation 1959. The second measure is concerned with the use and analysis of the data collected during the IGY. A Special Committee of the ICSU is formed to organize and carry through a specific programme of research. After the observations based on this programme have been completed the functions of the Special Committee come to an end. The exhaustion of the scientific content of the observational data is the responsibility of the Unions as the scientific members of the ICSU. The Special Committee for the IGY will therefore terminate its work on 1st July 1959, and the ICSU has appointed a Special Committee for Inter-Union Co-operation in Geophysics, whose task will be to deal with all aspects of the closing stages of the IGY enterprise, including the International Geophysical Co-operation 1959. Its activities will include publication, financing, and organization of international co-operation in the use and analysis of IGY data by the World Data Centres, the International Scientific Unions, the World Meteorological Organization, and otherwise.

The next large enterprise to be sponsored by the ICSU is in the marine sciences. Seven-tenths of the surface of the globe is covered by oceans, and the oceans present many problems that can be solved only by international co-operation. The ICSU therefore established in 1957 a Special Committee on Oceanic Research, representing an already existing organization, with the task of framing a programme of oceanic research; the countries that will collaborate in this programme will form National Committees to consider the contribution that they can make to the programme. The main fields of investigation have been considered in a preliminary manner by the Committee; it is planned that this programme should be implemented in the first instance with a survey of the Indian Ocean over a complete monsoon period in 1962–63. The Indian Ocean is the ocean about which least is known and, because of the two monsoon seasons, is the most suitable for certain fields of research. It is expected that at least twenty oceanographic research vessels will be in operation in the Indian Ocean during the period 1962–63. After the experience gained in this operation, it is probable that it will be continued in other ocean regions in later years.

The launching of instrumented earth satellites as a part of the IGY programme has opened a whole new era of space research. With the closing of the IGY the question arises whether international collaboration in space research should be continued under the auspices of the ICSU. Its national and scientific members were asked to give their views on the proposal that the ICSU should establish a committee on space research. The response was favourable, and the ICSU has appointed a committee on Space Research to function until the end of the year 1959. The primary purpose of this committee is to aid in the development of plans for space research on an international basis of free scientific activity. It will report to the ICSU the measures that are needed in the future to achieve the participation in international programmes of space research of all other countries of the world with those that are already actively engaged in research programmes involving the use of instrumented earth satellites and space probes. The Committee is instructed to keep itself fully informed on the activities of the United Nations and other international bodies in this field, in order to ensure that through such collaboration maximum advantage is accorded international space-science research.

Attempts to launch Moon probes have already commenced. Looking to landings on the Moon or planets in the foreseeable future, some scientists expressed concern lest such landings should be planned without adequate precautions to avoid undesirable contamination from terrestrial sources that might conceivably be prejudicial to certain lunar or planetary experiments of the utmost future interest and importance to science. This problem was brought before ICSU by a national member. The Bureau of ICSU appointed a Committee on Contamination by Extra-Terrestrial Exploration to specify conditions of landing that would keep contamination to acceptable levels. This Committee has produced an interesting report and has recommended that consideration

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should be given to framing a specific code of conduct, which should achieve a reasonable compromise between the perfectly proper ambition to start lunar—and possibly planetary—exploration at the earliest moment, and the need to safeguard future research. The Committee has been instructed to draw up such a code of conduct and to report its conclusions to the Committee on Space Research.

Two further activities of the ICSU in the field of international collaboration in science must be mentioned. Following the Unesco meeting on Science Abstracting held in Paris in 1949, the ICSU, at its General Assembly in Copenhagen in that year, appointed a Joint Commission on Physics Abstracting. In September 1950 this Joint Commission took over complete responsibility for co-ordinating physics abstracting from Unesco, and in 1951 it was transformed into a Special Committee of ICSU, designated the ICSU Abstracting Board—IAB. This Board works with the co-operation of established abstracting journals admitted as member journals to the Board, and on the principle that in any particular branch of science there should be only one abstracting journal in each language. The prompt publication of abstracts in physics has already been efficiently organized, and the Board is now actively functioning to unify the abstracting services in the field of chemistry. At the request of the Biological Abstracting Services it is now studying the enormous field of biology to ascertain how it can effectively improve the heterogeneous state of abstracting in that science. An important adjunct to the work of the IAB is the appointment of correspondents in each country.

A second important activity of the ICSU is the Federation of Permanent Astronomical and Geophysical Services, which, after extensive negotiations with Unesco, was organized under Statutes accepted by ICSU in 1956. This Federation (FAGS) is concerned with the various Permanent Services associated with the Unions of Astronomy, of Geodesy and Geophysics, and of Scientific Radio. These Permanent Services, which were previously supported or maintained by the Unions, with in some cases national support, are the following:

International Time Bureau;
International Latitude Service;
Permanent Service of Geomagnetic Indices;
International Gravimetric Bureau;
International Seismological Summary;
Monthly Bulletin of the International Seismological Bureau;
International Commission on Atmospheric Ozone;
Quarterly Bulletin of Solar Activity;
Central Ursigram Service.[1]

The future of the International Bureau of Atmospheric Ozone is now under discussion with the World Meteorological Organization. To these Services has recently been added a World Mean Sea Level Service. A proposal was received by the ICSU that a Joint Commission on World Geophysical Days should be established to continue some of the work done under the IGY World Days Programme, including the advance specification of Regular World Days and World Meteorological Intervals in a World Geophysical Calendar; the specification of a current schedule of solar activity alerts; and the preparation of a post facto calendar of significant indices and outstanding solar and geophysical events.

The General Assembly of the ICSU, at its meeting in Washington in October 1958, approved that an International Service for World Days should be established as a permanent service under FAGS and delegated its authority in the formation and subsequent functioning of this service to the International Union for Radio Science.

FAGS has its own Council and is in receipt of subventions from Unesco and also from the ICSU. The allocation of these subventions is made after consideration of the needs of the various services, in conjunction with the support that they receive from national or other organizations. It has been emphasized by the ICSU that the purpose of these Permanent Services is to supply fundamental data of various sorts that are required in many geophysical investigations, but not to undertake scientific research.

The ICSU under its present statutes has assumed great responsibilities, and its activities have greatly expanded in recent years. As it is entirely non-political, the organization of scientific affairs under its auspices is by scientists themselves, acting through their national academies and research councils. The ICSU is able to catalyse extensive research that would not otherwise be done. Through its special committees it can plan large programmes of research involving international collaboration, which are then organized through national machinery.

[1] A service for the transmission of coded ionospheric, solar, geomagnetic, and other geophysical data.

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Hearing in whales

F. C. FRASER and P. E. PURVES

Cetaceans have been found to have a highly developed intelligence, but little has been known until recently about their sensory apparatus. Their sense of hearing is now known to be highly developed, and the modifications that have occurred to the terrestrial mammalian ear in order to fit it for use under aquatic conditions are described in this article.

Cetaceans are mammals that have an exclusively aquatic mode of life. They are born, feed, move, and reproduce in the water. Until cetaceans were kept for more or less protracted periods in captivity little was known about their behaviour. Observation and experiment, mainly at Marineland, Florida, have shown that the dolphins kept there have a very high level of intelligence. 'In respect to emotional and motivational behaviour, the dolphin appears to fall somewhere in the range of development of dog and chimpanzee' [1].

It would be expected that the long-range sense receptors of the cetacean would be at least as highly developed as those of the higher terrestrial mammals. Cetaceans are almost or altogether without the sense of smell. In the baleen whales there are only reduced olfactory organs, while in the toothed whales not only are they absent but the olfactory lobes of the brain are completely atrophied.

There is evidence that the visual sense can be normally developed and adapted to underwater vision in conditions of good visibility, but there must be conditions of turbidity or depth in which the eyes cannot function. The first of these factors operates particularly among the primitive river dolphins, and it is significant that the eyes of these animals are very much reduced in size.

Experiments have, in fact, shown that in cetaceans the most discriminating of all the long-range perceptors is the sense of hearing. The lack of visible external ears and the extremely small calibre of the external auditory meatus have led many anatomists to the conclusion that some method of hearing other than that normal to terrestrial mammals must be involved. One of the reasons for this conclusion is that the whole approach to an interpretation of cetacean hearing has been conditioned by the anatomical and physical factors involved in human hearing.

The human ear (figure 1), in common with the ears of all terrestrial mammals, contains a mechanism for converting the relatively large displacement amplitudes of the air-borne waves received by the eardrum to movements that can be detected by the hair cells of the cochlea. The contents of the cochlea are almost entirely fluid, so that its acoustical properties approximate to those of water. Sound waves in air normally suffer displacement amplitude loss in passing into such a medium—and without the middle-ear mechanism there would be no displacement of the hair cells relative to surrounding structures and there would be no sensation of hearing.

Figures 1 and 2*a* shows the mechanism diagrammatically; the effect of the bony levers added to that of the difference in area between the eardrum and the stapes gives a sixty-fold increase in pressure at the fenestra ovalis,[1] corresponding to the sixty-fold increase in the pressure amplitude of a sound wave in water compared with that of a sound wave of the same frequency and intensity in air.

Anatomical investigations [2] have shown that, while the cetacean ear retains the essential mammalian components, they have been modified to function in the different physical conditions involved in the aquatic mode of life. The cochlea, apart from the ability to respond to ultrasonic frequencies, is similar to that of terrestrial animals, and it is the middle-ear mechanism that shows the modifications necessitated by the fact that the sound waves reaching the whale's ear are travelling through water. This mechanism must produce an increase in the displacement amplitude of the vibration while the relative areas of the structures must be such as to maintain the pressure amplitude at the same level as that in the surrounding water.

Figure 5 shows a dissection of the squamo-mastoid region of the head of a fin whale. Starting from the right, there can be seen the small aperture of the meatus penetrating the blubber. The aperture is about the diameter of a lead pencil

[1] This ratio is not accepted by all human anatomists, but in view of the physical properties of sound conduction in water we consider the figures quoted to be the more accurate. The evolutionary implications are of extreme importance.

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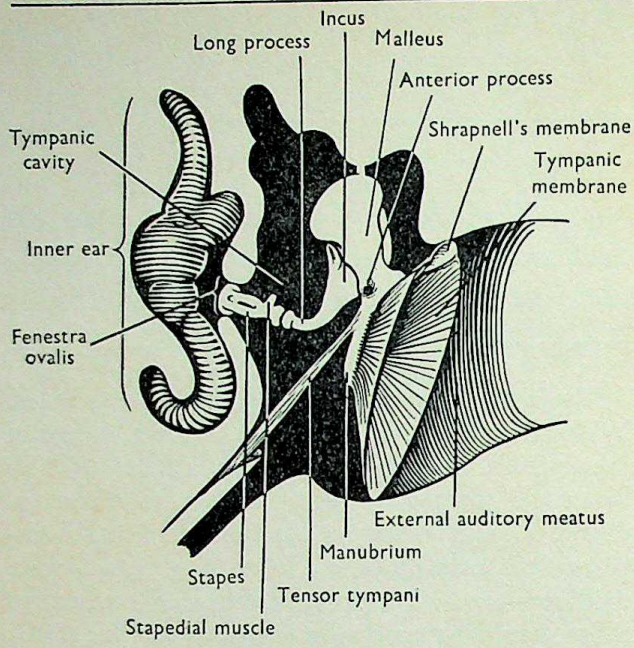

FIGURE 1 – *Diagram of the human middle ear.*

and is lined with black epithelium which is continuous with that of the external skin. The cartilages of the external ear and its related muscles are present, and are apparently functional although situated below the surface of the blubber. Thereafter the meatus is reduced for a distance of about six inches to a tightly stretched cord which lies in a groove in the mastoid. Further towards the tympanum the cord formed by the meatal corium develops into a tube filled by a dense mass of horny epithelium, referred to as the ear plug. At the tympanum this plug invests a structure resembling the finger of a glove, the homologue, in human anatomy, of Shrapnell's membrane (figure 1). In the toothed whales, with the possible exception of the sperm whale, the external meatus is open throughout its length, but it is much narrower, and is traceable in the dissected specimen as a thin black pigmented tube no more than a millimetre or so in diameter. In the dissection shown in the plate, half of the massive tympanic bulla has been removed to expose the middle-ear cavity with its associated air sinus. Figure 3 shows the middle ear and cochlea (C) of a fin whale and will be described with reference to figure 1, a diagram of the human ear. In the dissected whale's ear the tympanic bulla which forms the floor of the tympanum has been cut away to expose the auditory ossicles (M, ST), muscles, and other ear structures. The tympanic membrane of the human ear is a circular membrane slightly concave mesially, attached around its circumference to the tympanic annulus and, internally, to the handle of the malleus. The axis of vibration of the membrane lies at right angles to that of the manubrium of the malleus (see figure 2*a*). Shrapnell's membrane (GL) in the whale has become grossly enlarged to form the glove-finger. The tympanic membrane, extended and folded like a closed umbrella (see also figure 2*b*), forms what will subsequently be referred to as the tympanic ligament (TL). In the same process the manubrium of the malleus has become extremely shortened and thickened and the axis of longitudinal vibration of the tympanic ligament lies almost parallel with it—not at right angles as in terrestrial mammals. The anterior process (processus gracilis) of the cetacean malleus is greatly enlarged and of channel-girder construction. A junction of extremely thin bone along its lateral margin fuses the processus gracilis to the tympanic bulla. This edge of the anterior process is buttressed by a stout projection of the tympanic annulus—the sigmoid process (SP). In the cetacean the long process of the incus is also

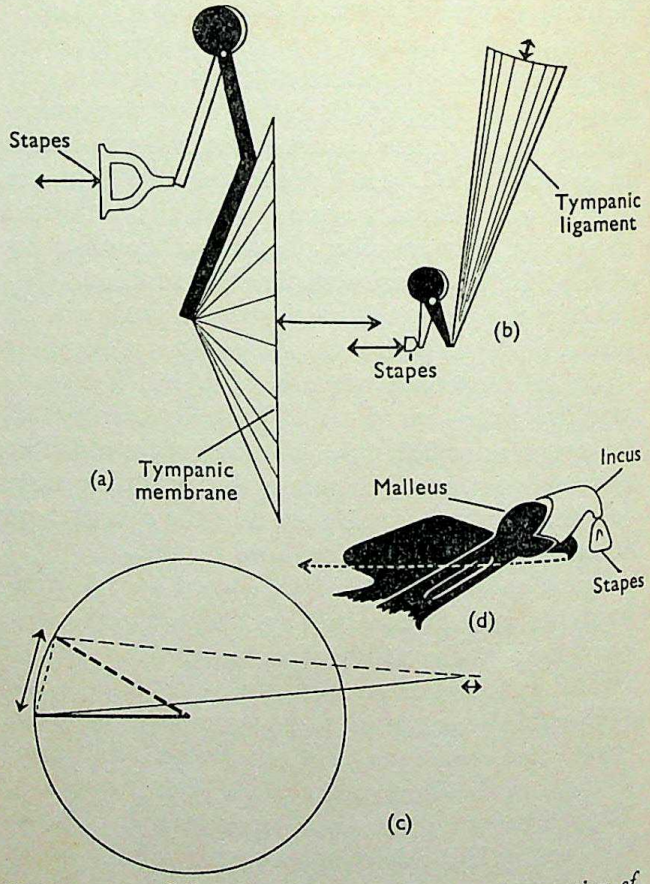

FIGURE 2 – *Schematic drawing of mode of operation of human and cetacean tympanic membrane and auditory ossicles. (a) Human ear drum and ossicles. (b) Cetacean ear drum (tympanic ligament) and ossicles. (c) Crank action of tympanic ligament of cetacean. (d) Angular articulation of malleus and incus in the cetacean. The dotted line shows line of traction of the tympanic ligament. (By permission of the Trustees of the British Museum.)*

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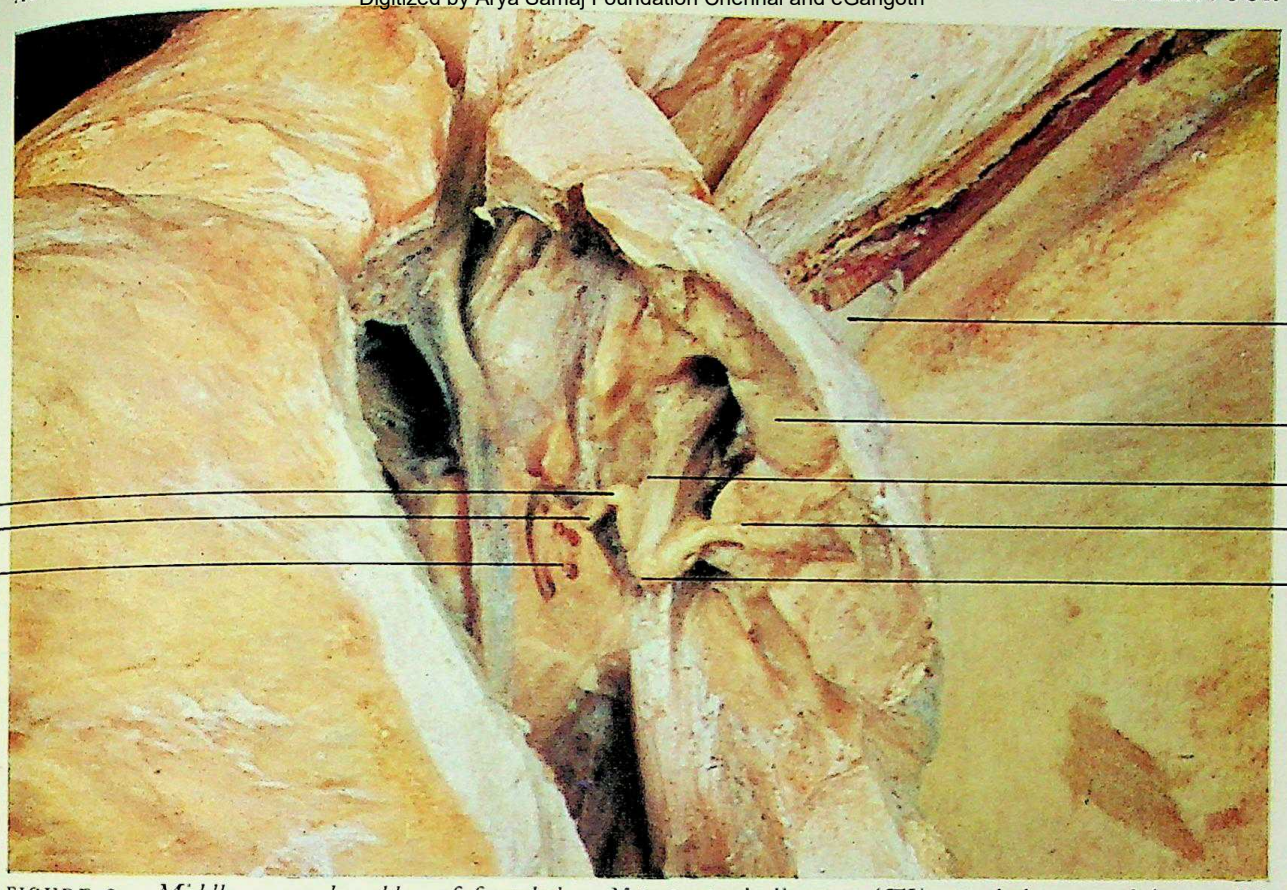

FIGURE 3 – *Middle ear and cochlea of fin whale. Note tympanic ligament (TL) attached to manubrium mallei (MM), processus gracilis fused to the bulla and sigmoid process (SP), the tensor tympani lying to the right, and carotid artery to the left of the cochlea (C); the incus (I) is visible to the left of the tympanic ligament, the muscle of the stapes (ST) lying in a groove above the latter. Note also the muscle mass (M), the tendon of which passes through the tympanic annulus to the internal face of the glove-finger (Shrapnell's membrane, GL).*

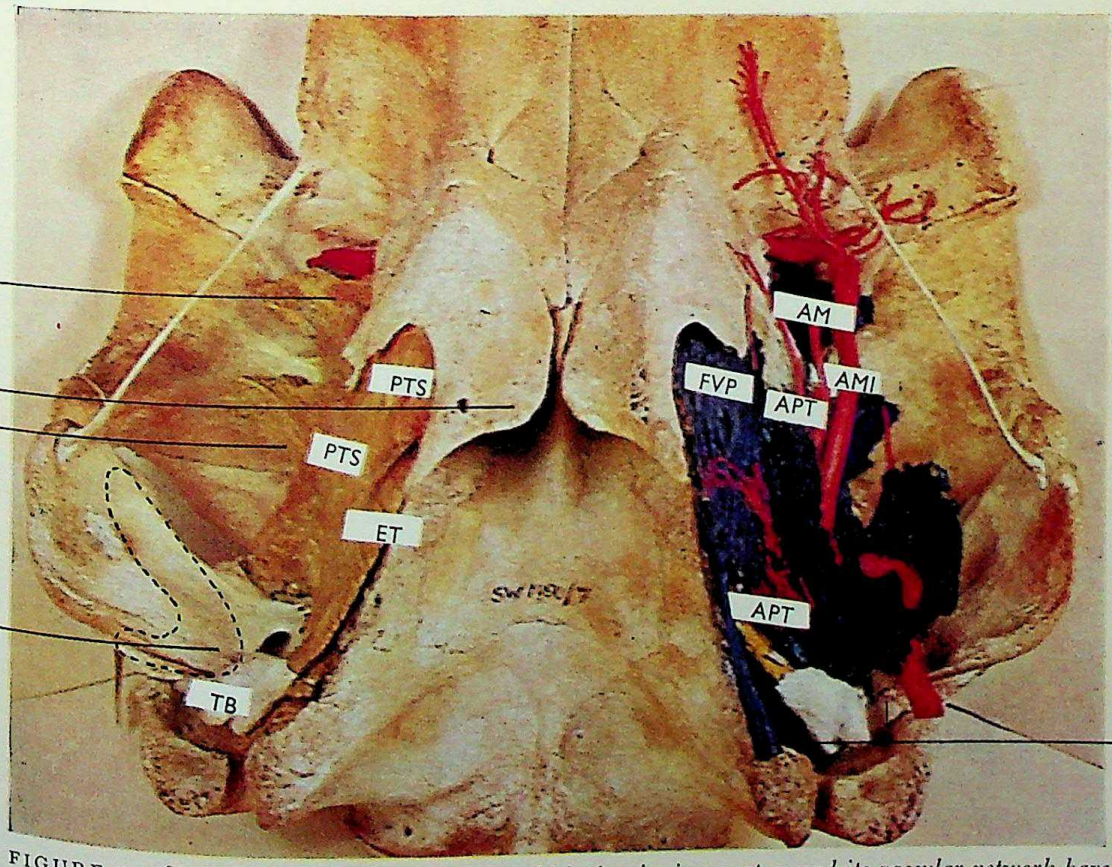

FIGURE 4 – *Skull of a young pilot whale in which the air sinus system and its vascular network have been injected with polyester resin.*

AM Mandibular artery
AMI Internal maxillary artery
APT Pterygoid artery. Arterial branches to internal pterygoid muscle
ET Eustachian tube
FVP Fibro-venous plexus
MS Middle sinus
PBS Peribullary sinus
PT Pterygoid bone
PTS Pterygoid sinus
PTS(PR) Preorbital lobe of pterygoid sinus
PTS(PO) Postorbital lobe of pterygoid sinus
TB Tympanic bulla

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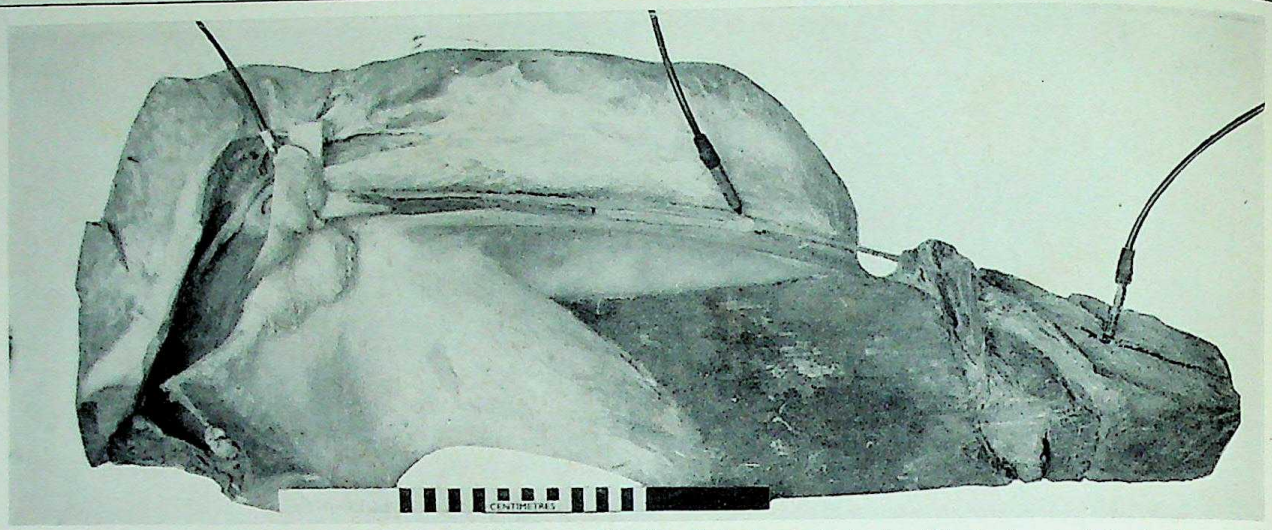

FIGURE 5 – *Dissection of the external and middle ear of a fin whale (ventral view). The probes used for testing sound conductivity are shown in situ.*

considerably shortened as compared with that in man. Quoting from Gray's 'Human Anatomy': 'The handle of the malleus follows all the movements of the tympanic membrane while the malleus and incus rotate together about an axis which runs through the short process of the incus and the anterior ligament (and therefore the processus gracilis) of the malleus. When the tympanic membrane and handle of the malleus move inwards the long process of the incus also moves in the same direction and pushes the base of the stapes towards the labyrinth' [3]. A mechanical study of the ossicles shows that this description is true also for cetaceans, with one important difference. In these the tympanic ligament is attached only to a point at the tip of the manubrium of the malleus, making a sharp angle with the latter in the manner referred to above. In these conditions the ligament acts like a piston rod attached to a crank, so that any small movement of the meatal end of the ligament produces a relatively large movement of the tip of the manubrium and therefore of the tip of the long process of the incus (figure 2*c*). Experimental evidence has shown that this amplification is in the region of 30 : 1, as compared with the approximately 2 : 1 reduction in the human ear.

In order that this amplification should be produced, the effective movement of the malleus must be solely rotational, and this is achieved by the stout channel-girder construction of the processus gracilis and its mode of fusion to the tympanic ring. The buttressing effect of the sigmoid process ensures that lateral movement of the malleus by the ligament is obviated and that the processus gracilis is capable of torsional vibration only. The angular articulation of the malleus with the incus (figure 2*d*) produces a condition in which there is positive oscillatory drive by rotation only. The smooth, curved surfaces of the facets tend to slip over one another in one or both directions when the oscillation is longitudinal, or transverse to the processus gracilis. This factor is of great importance in the exclusion of vibrations other than those of the tympanic ligament. The amplification described above involves a thirty-fold reduction of power. In order to compensate for this, the foot of the stapes has an area approximately one-thirtieth of that of the distal end of the tympanic ligament. The ratio of the area of the foot of the stapes to that of the distal end of the tympanic ligament is thus equal to the ratio of the area of the foot of human stapes to that of the eardrum. Whereas in man the resultant pressure increase at the stapes compensates for the power loss due to the gaseous environment, in cetaceans it compensates for the power loss due to the displacement amplitude produced by the ossicular leverage.

In order to demonstrate the amplification feature of the cetacean malleus the following experiment was performed. A thin steel wire was soldered to one end of a conical transducer containing a barium titanate ceramic, and the other end was attached to the tip of the manubrium of the malleus at the normal point of attachment of the tympanic ligament, so that it simulated the latter in length and position (figure 6). The angle of attachment of the wire could be altered by raising or lowering the transducer relative to the position of the manubrium, while the tension was kept constant by attaching a small weight to the cable which ran over a pulley and connected the

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variable-frequency oscillator and transducer. The incus was allowed to rest on the malleus in its natural position, separated from it by a thin film of petroleum jelly. The stapes was simulated by the stylus of a microgroove crystal pick-up which was connected to an amplifier and cathode-ray oscilloscope. The frequencies used in this experiment lay between 10 and 100 kc/sec. A considerable difference was noted in the height of the deflection of the time base in relation to the angle which the wire made with the long axis of the manubrium mallei. When the wire was pulling at a sharp angle, one of approximately 5°, the deflection was about ten times the height attained when the wire was pulling at right angles to the manubrial axis. With the wire pulling at right angles to the manubrium the ratio between the displacement amplitude of the crystal face and that of the tip of the manubrium would be unity, and it would increase as the angle of attachment of the wire diminished, until it approached infinity with the wire almost parallel to the axis of the manubrium. This method of amplification is to some degree self-compensating, since the smaller the displacement amplitude of the sound wave the greater the relative amplification.

ADAPTATION FOR DIRECTIONAL HEARING

Directionality is probably the most important of the attributes of hearing to animals in general. In terrestrial mammals, because of the difference in physical properties between the body tissues and the ambient air, the greater part of the sound energy impinging on the head is dissipated, only the part that is received at the external ear being transmitted to the cochlea. Mobility of the head, movements of the external ears, and their degree of separation, all provide differences of intensity, quality, time, and phase between the ears as factors in directional hearing. In cetaceans, because of the relatively close similarity between the acoustical properties of their body tissues and water, nearly all the sound energy impinging on the body is transmitted. To achieve the separation of the ears required for directionality, therefore, acoustic isolation of the two cochlea from the

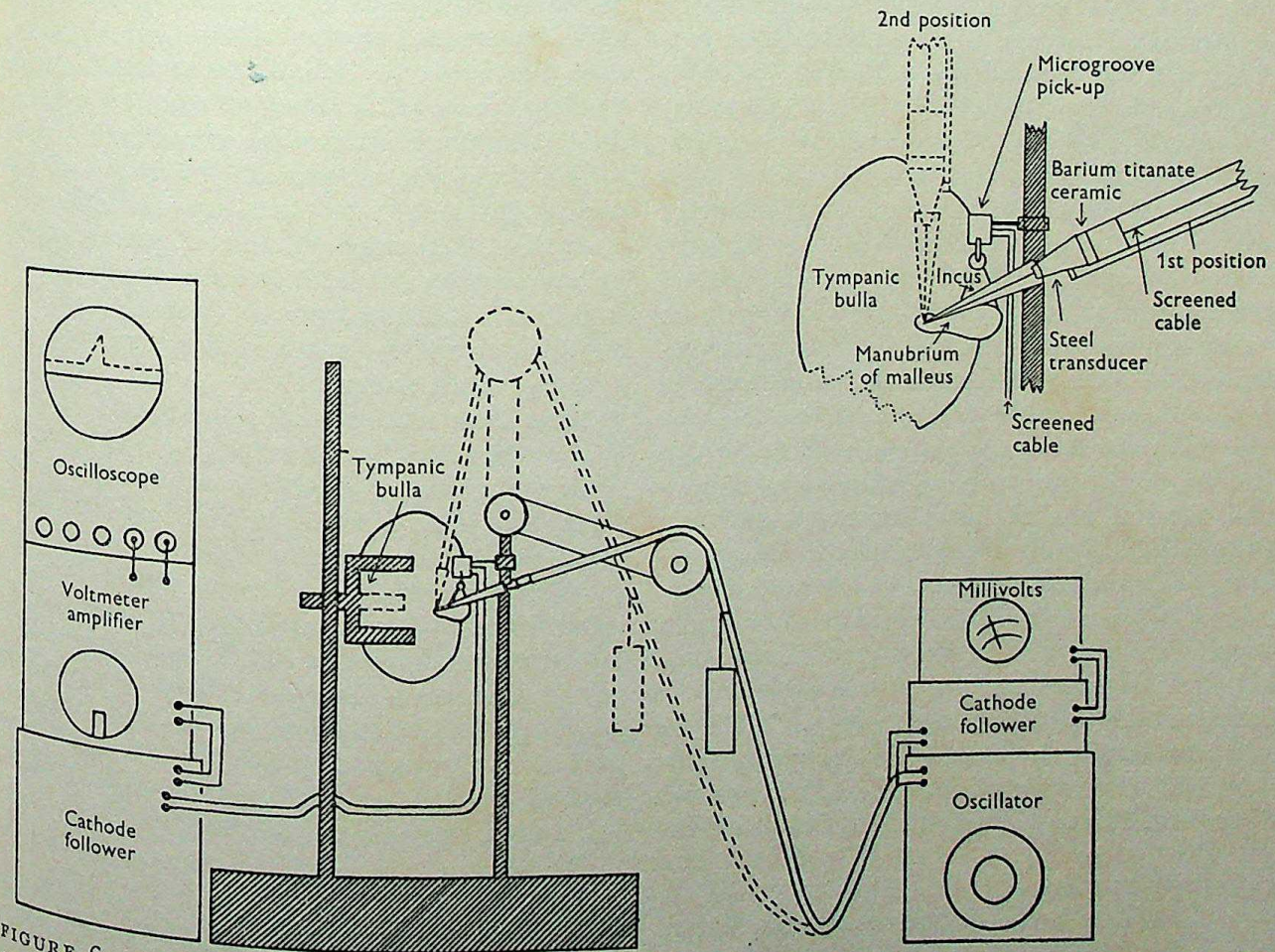

FIGURE 6 – *Apparatus for demonstrating changes in the amplitude of torsional oscillations of the malleus when actuated by a simulated tympanic ligament vibrating longitudinally at various frequencies and angles of traction. (By permission of the Trustees of the British Museum.)*

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rest of the body is essential. It is believed that the auricular muscles, those of the sinus system, and the sinus system itself are brought into operation for appreciation of intensity and quality differences. Because of the greatly increased velocity of sound in water, and its reduced attenuation, directional hearing also involves increasing the range of sensitivity of the ear to accommodate high-pitched and ultrasonic frequencies, the wavelengths of which are small compared with the linear dimension of the head.

During the evolution of the cetacea from their terrestrial ancestors the tympano-periotic (TB, figure 4) has become completely dissociated from adjacent bones of the skull. Moreover, the bones surrounding the periotic have been excavated and eroded by pneumatized extensions of the middle-ear cavity so that the periotic is enveloped in a system of air-filled sacs (PBS). Anteriorly to the periotic, the extension of the middle-ear cavity has split each pterygoid bone into two laminae, which in many species have become widely separated. The extensions in the more advanced species have developed beyond the pterygoid bones and have invaded the preorbital (PTS (PR)) and post-orbital (PTS (PO)) regions of the skull base (figure 4). In the common dolphin they have penetrated the elongated snout almost to its tip. In the more primitive dolphins the whole or nearly the whole of the outer bony lamina persists, but as specialization has proceeded the bony lamina has become perforated and fenestrated, and has finally disappeared. During the process of removal of the calcified elements of the bone, the blood vessels and periosteum have remained and hypertrophied so that the whole air sac system is contained within a tough fibro-elastic network of blood vessels and a periosteal sheath. The sacs are lined by an extension of the middle-ear mucous membrane with abundant glands and mucous ducts, between which is a layer of ciliated epithelium. Under conditions of normal atmospheric pressure the fibro-elastic walls of the veins of the vascular plexus are pressed closely together, in this respect differing from non-fibrous elastic veins in other parts of the body, which are normally turgid at all conditions of pressure. The whole system of air spaces is filled up by an extremely stable foam, the liquid phase of which is a finely divided mucus–oil emulsion secreted by the mucous membrane that is present as a lining. With the increased hydrostatic pressure involved in diving, the sinus spaces are diminished in volume and the evacuated space is filled by injection of blood into the vessels of the fibrovenous plexus (FVP). By this process, equilibrium is maintained between the gaseous pressure in the tympanic cavity and the hydrostatic pressure external to the tympanic ligament. By the same process an air envelope is maintained round the periotic, for acoustic isolation, and round the auditory ossicles and fenestra rotunda to allow for the displacement amplitudes previously described.

The efficiency of such a layer was tested experimentally. A similar type of foam was compressed to 100 atmospheres and observed through an optical cell. The bubbles were greatly diminished in volume but were still observable after 20 minutes at this pressure. This implies that a residual film of air would persist throughout the sinus system at all conditions of pressure likely to be experienced by the cetacean, providing the ideal conditions for sound dissipation, with the implications of differences of quality, intensity, time, and phase between the two ears.

The foregoing simplified description of the system does not take into account either the voluntary functioning of auricular, pterygoid, and palatal muscles or the involuntary action of the stapedial and tensor tympani muscles (figure 3), all of which are important in direction-finding.

It has been suspected for several years that cetaceans use echo location, and recent work by W. E. Schevill and B. Lawrence [4] and by W. N. Kellogg [5] have established conclusively that it is used. The echo-location method consists of the transmission and reception of an intermittent pulse with a variable recurrence frequency comparable with that used by bats. There is evidence also that cetaceans can discriminate the quality of echoes with a high degree of accuracy. Judged by the great development of the brain of these animals it would not be surprising if it is found that they have a complete sound picture derived from purely auditory sensations.

REFERENCES

[1] McBride, A. F. and Kritzler, H. *J. Mammal.*, 32, 251, 1951.

[2] Fraser, F. C. and Purves, P. E. *Bull. Brit. Mus. (nat. Hist.)*, 2, 103, 1954.

[3] Johnston, T. B. and Whillis, J. (Editors). 'Gray's Anatomy' (29th edition). London, 1946.

[4] Schevill, W. E. and Lawrence, B. *Breviora*, No. 53, 1956.

[5] Kellogg, W. N. *Science*, 128, 982, 1958.

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The interior of the Earth as revealed by earthquakes

I. LEHMANN

The study of seismic waves resulting from earthquakes has long been a means of investigating the inner structure of the Earth. Recent improvements in recording instruments and in methods of analysing results obtained by them have added considerably to knowledge in this field, although much still remains to be done. Analysis of the waves resulting from atomic explosions offers a new way of progress, of which some advantage has lately been taken.

The deep interior of the Earth is inaccessible, and no rays of light penetrate to let us see what is below the surface. But rays of another kind penetrate and carry with them their messages from the interior. The Earth has been found to have elastic properties that allow movement set up at the source (focus) of an earthquake to radiate into the interior and to spread over the surface. In a strong earthquake the whole of the Earth is set vibrating. At some distance from the focus, depending on the strength of the shock, the movement is no longer perceptible, but sensitive seismographs can record the waves that emerge at the surface. The records provide data from which knowledge of the Earth's interior may be gained. From seismic studies we have learned that the Earth consists of a core surrounded by a mantle on which there is a crust; inside the core there is a small inner core (figure 1).

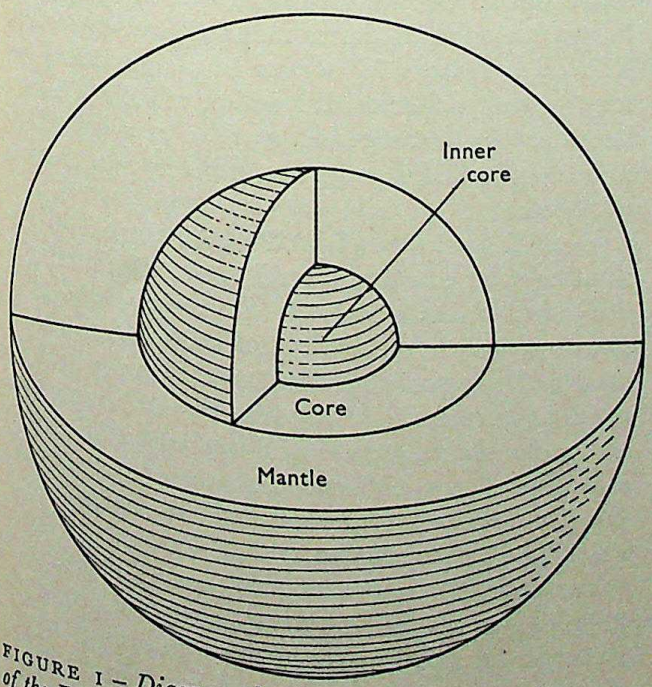

FIGURE 1 – *Diagram showing mantle, core, and inner core of the Earth.*

Towards the end of the nineteenth century it was realized that earthquake movements extend to great distances from the focus. Systematic recording of earthquakes began, and the very important results gained at an early stage greatly stimulated interest in this new science.

The elastic waves that radiate into the Earth are of two kinds, having different speeds of travel: P waves (*undae primae*), in which the particle motion is longitudinal, and S waves (*undae secundae*) with transverse particle motion. The speed of S waves is roughly 60 per cent of that of P waves. The arrivals of the waves are marked by groups of oscillations in the seismograms, and at moderate distances from the focus they usually stand out clearly. The seismogram of figure 2 was obtained at a distance of 18·6° from the focus.[1] P and S appear on it. The large oscillations succeeding S are due to surface waves.

We measure the arrival times of the waves today usually with an accuracy of not less than 1 second, and deduce the travel times of the waves from focus to recording station, if the location of the focus and the time of occurrence of the earthquake can be found. When a fair number of travel times to points at different distances from foci at approximately the same depth (the normal depth is about 10–20 km) are available, time-distance tables can be set up, giving the travel times of each type of wave over the various distances. It is customary to present them as time-curves.

The first attempts to construct time-curves for the P and S phases revealed that the average

[1] Distances in seismology are angular distances subtended at the centre of the Earth, as a first approximation taken to be a sphere.

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speed, as determined along the chords, increased with focal distance, indicating that the wave velocity increased with depth. As a consequence of this the rays are not straight lines but have an upward curvature.

At about 100° focal distance P and S became small and at somewhat greater distances could not be detected. Clear P phases reappeared at about 140°, but they had been delayed, so that their travel times did not fit on to the continuation of the time-curve for shorter distances. This observation was made in 1906 by R. D. Oldham, who drew the conclusion that deep in the Earth there was a decrease of velocity, causing the rays to bend downwards so as to leave part of the Earth's surface in shadow. He attempted to calculate the depth at which the decrease of velocity occurred, but his observations were not good enough for this purpose; therefore his results were very much in error. E. Wiechert, in Göttingen, had also come to the conclusion that the Earth had a core in which the velocity was smaller than in the surrounding mantle. It was the first great achievement of B. Gutenberg to establish this beyond doubt by means of records of distant earthquakes obtained on the Wiechert seismographs at Göttingen, and to calculate the radius of the core. His result did not differ much from later ones obtained from modern and more abundant data.

Gutenberg made use of the time-curves for P and S up to about 103° established by Wiechert and Zöppritz, and of the wave velocities derived from them. At that time formulae had been developed by means of which transmission times to different distances could be calculated when the velocity as a function of the distance from the Earth's centre was known, and also formulae by means of which the wave velocities as a function of depth could be obtained when the time-curve was known. The ray emerging at the distance where the P curve broke off would graze the core.

The belated P waves observed from a little beyond 140° onwards had passed through the core, but the velocity of these waves in the core could not be derived from the formulae used for the mantle, for these formulae break down when there is a discontinuous decrease of velocity, as at the core boundary. But when a velocity distribution in the core was assumed the travel times could be calculated and Gutenberg varied his assumptions until the calculated travel times agreed with those observed. The velocity as a function of depth was then known for the whole of the Earth to a first approximation.

On theoretical grounds it was to be expected that the rays would be reflected on reaching the surface of the Earth and would be reflected and refracted at discontinuity surfaces in the interior, such as the boundary of the core, partly as rays of the same kind and partly transformed into rays of the other kind (P into S and vice versa). Thus at great distances from the epicentre (the point on the Earth's surface directly above the focus) waves would be arriving along many different paths, producing oscillations in a seismogram and marking phases more or less prominent according to the energy carried. When the velocity distribution within the Earth is known, it is possible to calculate the transmission times along all the different paths.

When earthquake records are examined a great many of the anticipated phases can be identified, but some of those originally expected to be present are not found, namely all those that would have come as S waves through the core. Since phases may be present without being very clear, many years passed before it was definitely concluded that transverse waves were not transmitted through the core. At the surface of the Earth a fluid does not transmit transverse waves, and therefore we say that the core is fluid, although in other respects it may not resemble a fluid as we know it.

The shadow zone for the P phase extends from about 105° to 143° epicentral distance. With modern highly sensitive instruments the P phase is found not to be completely absent in this range: in strong earthquakes it is usually faintly recorded. The appearance of P waves in the shadow zone may be due either to diffraction around the core boundary or to a spreading of the rays caused by a small gradual decrease of velocity just outside the core.

In addition to this faint P phase there is, in the shadow zone, another later P phase that is faint at the smaller distances. On Gutenberg's original Earth model its presence could not be explained, and it was vaguely ascribed to diffraction. However, as seismographs improved it was more and more clearly recorded, and an explanation was required. In 1936 the writer pointed out that the presence of a small inner core in which the P velocity was greater than just outside it would fully account for the occurrence of the phase, for it would cause incident rays to bend upwards strongly enough for part of them to emerge in the shadow zone. Gutenberg and Richter accepted the existence of this inner core and calculated its

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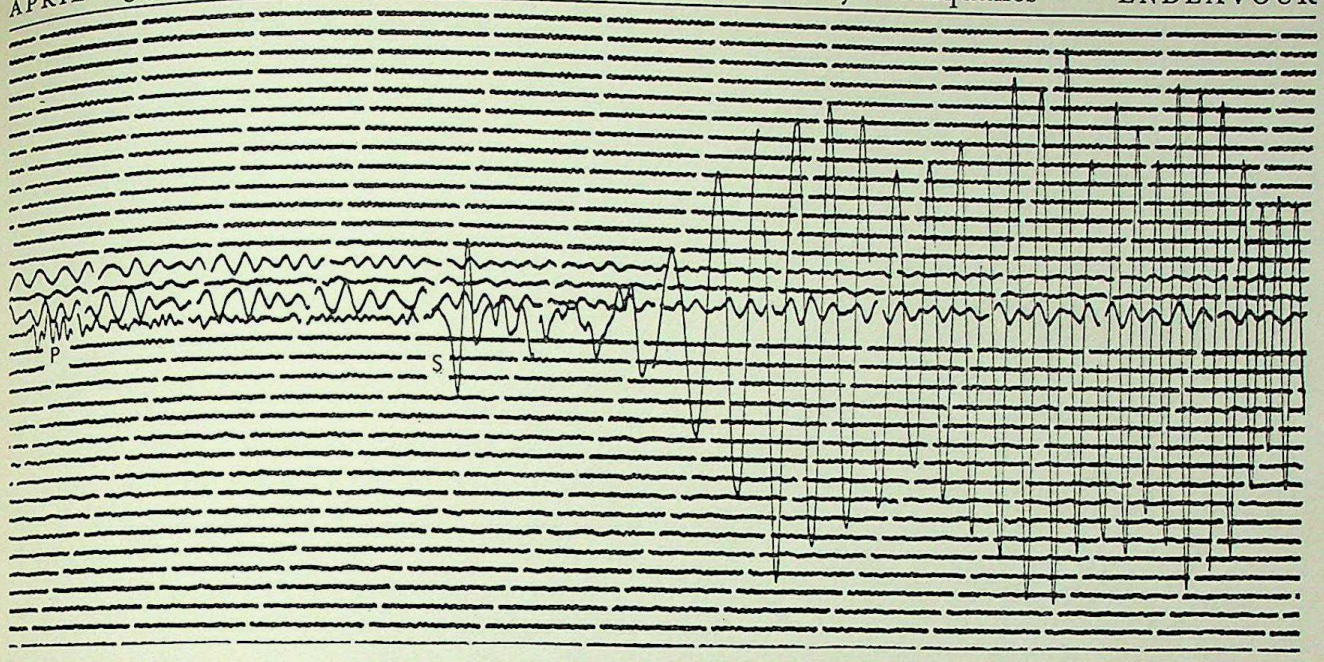

FIGURE 2 – *The earthquake of 23rd July 1929 recorded at Copenhagen at epicentral distance 18·6°.*

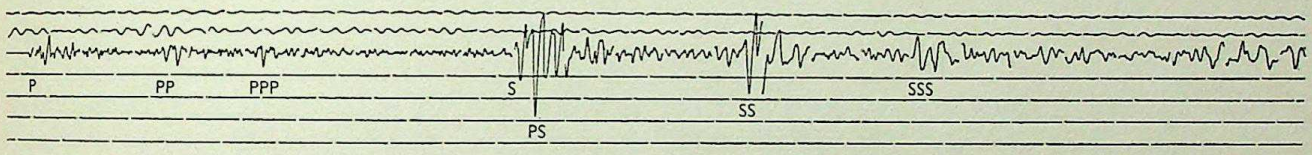

FIGURE 3 – *The earthquake of 30th June 1936 east of Kamchatka recorded at Copenhagen at epicentral distance 70·1°.*

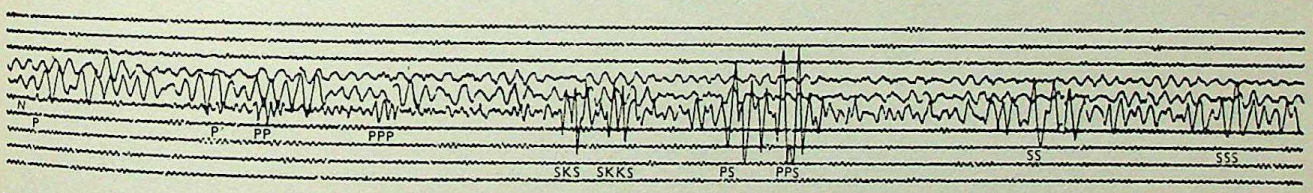

FIGURE 4 – *The earthquake of 1st March 1948 off the west coast of New Guinea recorded at Scoresby-Sund at epicentral distance 108°.*

radius and the velocity distribution in it. Later H. Jeffreys proved that diffraction could not account for the phase in question.

Figure 3 is part of a seismogram recorded at an epicentral distance of 70·1°. PP, SS and PPP, SSS are, respectively, phases due to waves reflected once and twice at the surface of the Earth. PS starts as P and is reflected as S.

Figure 4 is part of a seismogram recorded at an epicentral distance of 108°. P′ is here the P wave reflected at the boundary of the inner core. SKS starts as an S wave, traverses the core as a P wave, and is again an S wave after leaving the core. SKKS is also an S wave outside the core and a P wave inside, but it is reflected when, from inside, it meets the core boundary. Figure 5 shows the paths of the rays corresponding to some of the phases of figure 4.

In figure 6 are seen the time-curves of the phases already mentioned and of a few others. PKP is the same phase as P′. A great many more phases occur, especially at great epicentral distances.

The fact that on the mantle there is a crust differing distinctly from it was shown by A. Mohorovičić in 1909; the boundary between crust and mantle is called the Mohorovičić discontinuity. The wave velocity in the crust is smaller than in the mantle underneath, and therefore the waves coming through the crust are refracted and bent upwards when they meet the mantle. There will be a range of distance within which both the refracted and the direct waves emerge, as indicated in figure 7; at a certain distance the refracted wave overtakes the direct wave because it travels faster in the lower layer. But its path is longer, and energy is lost on refraction, and therefore the corresponding phase in a seismogram will be smaller than that due to the direct wave. There

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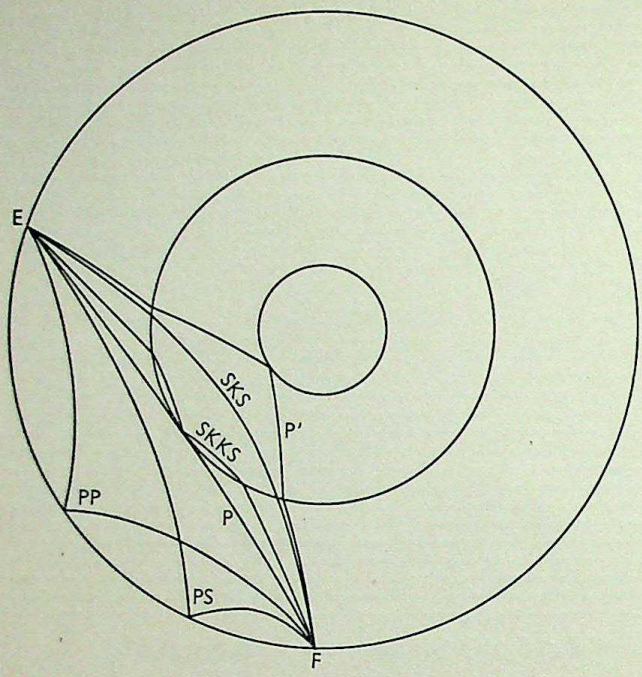

FIGURE 5 – *Rays from focus F to epicentre E at distance* 108°.

therefore appears a small P phase succeeded by another much larger P phase. This was observed by Mohorovičić, who gave the correct interpretation. He was interested in finding the depth of the discontinuity but did not have the means of determining it with any accuracy. Actually it turned out to be extremely difficult to arrive at reliable values for the depth, though many different methods were employed. The best results have been obtained from explosions, which can be looked upon as artificial earthquakes. They can be timed with great precision, and the focus is exactly known; when they are well recorded at suitable distances more useful data are obtained than can be derived from earthquakes. It now seems to be established that the discontinuity is at a depth of between 30 and 40 km under most continental areas. Under the deep oceans it is at a much smaller depth, only about 10–15 km under the water surface.

While the evidence for the existence of the Mohorovičić discontinuity and of the other subdivisions of the Earth mentioned above is very clear, precise determination of their depths is difficult. It depends on very precise determination of the velocity variation throughout the Earth, and this in turn depends on precise determination of the travel times of the direct P and S waves and of some of the reflected and refracted waves. Much important work has been done along these lines, a great deal of it in the 1930s. In the course of this work it appeared that subdivisions of the mantle have also to be considered, but the evidence for them is not of a very precise nature, and their location is uncertain.

It is a difficult and lengthy process to construct good time-distance tables or time-curves. To obtain accurate travel times we require to have the focus and the time of occurrence of the earthquake accurately determined. As a rule this cannot be done directly, because there are not enough observations close to and around the epicentre. It is therefore necessary to make use of time-curves already in existence, and there is then the risk of transferring errors from these curves to the new travel times. When time-curves have been determined from them it may therefore be desirable to have the elements of the earthquakes redetermined and the whole process repeated.

For the construction of the time-curves it has been customary to use a graphical method, plotting travel times against distance and drawing a smooth curve through the cluster of points thus obtained. It is a somewhat arbitrary process, and, in common with other smoothing procedures, it is apt to smooth away or faultily to introduce changes of slope or curvature. This is serious,

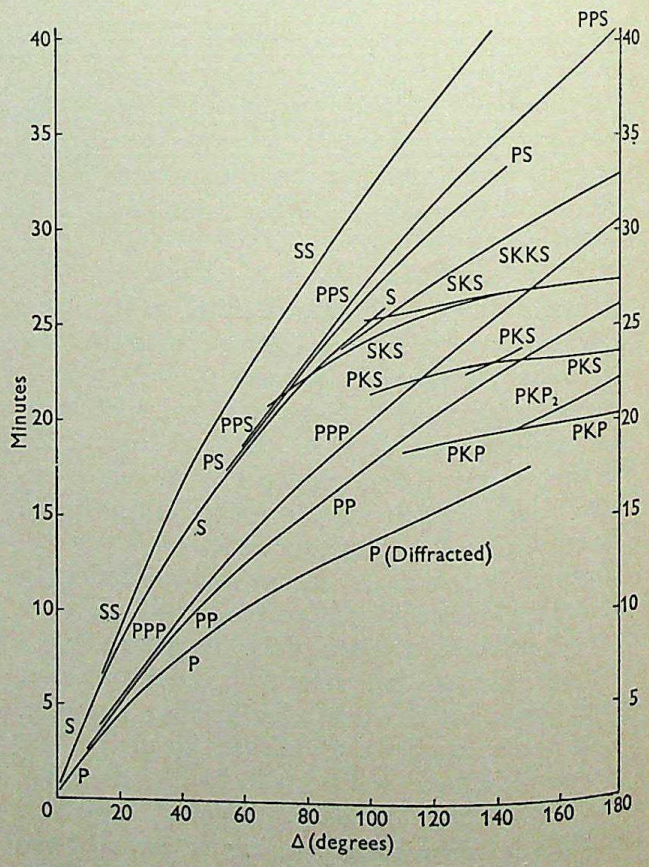

FIGURE 6 – *Travel times for a surface focus (Jeffreys-Bullen,* 1940).

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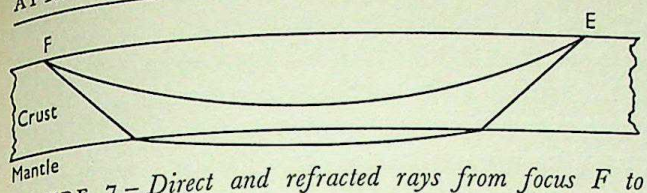

FIGURE 7 – *Direct and refracted rays from focus F to epicentre E.*

because it is such changes that indicate the existence of more or less abrupt changes of velocity or velocity gradient in the Earth. Many time-curves have been constructed in the course of time, and the existence of various so-called discontinuities has been derived from them.

Two sets of time-distance tables or time-curves are now available which are far better than any previous ones. They are due to Gutenberg and Richter and to Jeffreys and Bullen. In 1928 Gutenberg published his *FrankfurterLaufzeitkurven* based on a large number of observations. In collaboration with C. F. Richter he greatly extended the work. In 1936 they jointly published the first part of 'On seismic Waves', containing time-curves for a great many phases. Amplitude variation was considered for the fixing of the distances at which the curvature of the time-curve was either greater or smaller than usual. The amplitudes of the recorded waves should be relatively large at the distances where the time-curve bends strongly, and amplitudes should be small where the curve is straight. Amplitudes were measured and used, and although very precise information is not derivable in this way, some useful indications were obtained.

The readings of the seismic records from all over the world are collected and published in 'The International Seismological Summary' (I.S.S.), for which foci and times of origin of individual earthquakes are determined. For the reduction of the data down to 1928 inclusive the Zöppritz tables were used, but it became more and more apparent that the times given by these tables departed seriously from actual travel times.

In 1928 Jeffreys began his very important work on travel times by a preliminary revision of the Zöppritz tables, using I.S.S. data. Later he undertook a thorough revision in collaboration with K. E. Bullen. A great quantity of data was used, and for the first time statistical methods were applied and the accuracy of the results obtained was evaluated. This implied difficult and extensive work because of the complicated processes involved. In part, new methods had to be developed. After the main work many special investigations followed, improving somewhat the first results. In 1940 the Jeffreys-Bullen (J-B) 'Seismological Tables' were published, and these are now being used for the I.S.S.

From these tables Jeffreys calculated the variation of velocity with depth (figure 8). On the whole, the velocities of P and S waves increase down to the core boundary. Jeffreys found the velocity of P waves to be 5·6 km/sec in the upper crust, below the sediments, and to be 13·6 km/sec at the core boundary, where it decreases to 8·1 km/sec. With increasing depth the velocity increases steadily in the outer core to about 10·4 km/sec. In the inner core it is nearly constant at 11·2 km/sec.

The velocity does not increase uniformly with depth all through the mantle. In the uppermost mantle the velocity increases slowly, but at a depth of a few hundred kilometres a strong velocity increase sets in, as indicated by a bending of the time-curve around 20° epicentral distance. Below a depth of about 1000 km the velocity again increases more slowly.

On the whole, the velocities as derived from the Jeffreys-Bullen tables are probably not far wrong, but there are serious uncertainties. This is chiefly because it is so difficult to determine the slope of the time-curve accurately. The boundaries of the mantle regions in which the velocity gradients differ are indicated by changes of slope and curvature of the time-curve, but our data are not accurate enough for us to say exactly where these occur. It has been found particularly difficult to determine the velocity variation near the boundary of the inner core.

A vast amount of data, in part more reliable, has accumulated since Jeffreys and Bullen constructed their tables. New seismographs have been developed, from the records of which the arrival

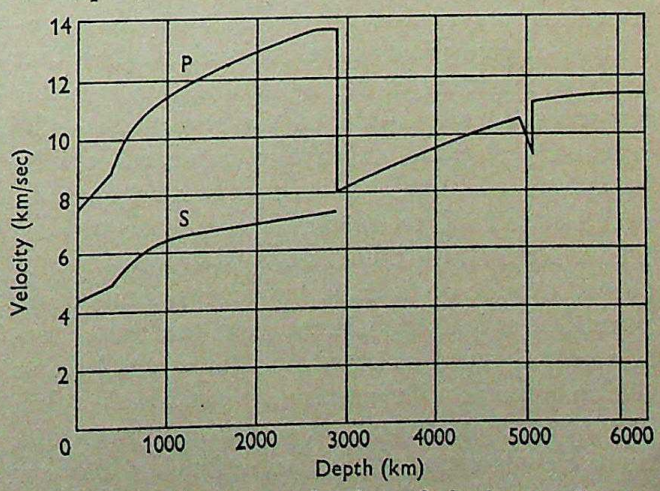

FIGURE 8 – *Velocity as function of depth according to H. Jeffreys*, 1939.

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times of the phases can be read with greater precision. In addition, explosion work has entered the picture. It has for a great many years been used for the exploration of the crust, especially for the finding of oil; since the second World War more effective explosives have been available, and many of the explosions have yielded results also for the upper mantle. Some large accidental explosions have also provided seismologists with new data. It was then found that the velocity just below the crust was greater than that derived from the Jeffreys-Bullen tables. Jeffreys drew attention to this, and in later work he provided corrected P tables for distances up to 30° for Europe. For, to complicate matters, it turned out that there were regional differences not only in the crust but also in the uppermost mantle. From the new tables it appears that the strong increase of velocity gradient in the mantle at first placed near 400 km depth is likely to occur at a much smaller depth, probably between 200 and 250 km. However, attempts to fix the depth accurately have as yet met with unsurmountable difficulties.

The study of the Earth's interior is approached from many different directions. The upper mantle plays an important part in many investigations, and geophysicists in various fields look to seismologists for precise and detailed information. Have we any means of supplying such information?

K. E. Bullen's presidential address to the International Association of Seismology and the Physics of the Interior of the Earth at Toronto in 1957 had the title 'Seismology in our Atomic Age'. He pointed out that atomic explosions had far greater energy than the chemical explosions it is possible to use, and that they send waves deep into the interior of the Earth. Some atomic explosions have been recorded by seismographs, but there has been a reluctance by the authorities concerned to give prior information about the exact location and time of the explosions. Though this has reduced the value of these explosions for seismological purposes, a few important results have been obtained, results that seemingly could not be derived from earthquake observations. There is no doubt that if an opportunity arose to record atomic explosions, by many seismographs placed at suitable distances from the source, information would be obtained that would help us to solve the problems that now confront us. We are here, as Bullen said, in a tantalizing position, for the tools we so much need exist, but they are not very likely to be placed in our hands. With ever-increasing fear of the perilous effect of atomic explosions, seismology can scarcely hope for any to be organized for its special purposes. However, if the intention to explode bombs for other purposes is made known beforehand and the location and time are communicated, as has been the case in some recent instances, it should be possible for seismologists to make some use of them.

It is also well to remember that great masses of earthquake data are as yet unreduced and that, skilfully handled, they may yield fruitful results. New methods are also forthcoming in earthquake studies. The surface waves, not dealt with here, spread over the surface of the Earth, but they penetrate to some depth below it; in large earthquakes they may penetrate to considerable depth. The intense study of surface waves carried out in recent years, especially at the Lamont Geological Observatory, has provided a new approach to the exploration of the crust and the upper mantle.

While seismology teaches us a great deal about the interior of the Earth there is certainly very much more we should like to know. If we ask what are the materials inside the Earth, in what state they are, what is their density, and so on, seismology alone does not supply the answer. We have to look to other branches of geophysics and to other sciences such as geology, the physics and chemistry of the Earth's interior, and also to astronomy for additional information. Much attention has been given to pertinent questions in recent years, but the results are, in part, highly controversial.

Important results on the density variation throughout the Earth were obtained by K. E. Bullen. The velocities of the seismic P and S waves depend on the density of the transmitting material and on the elasticity as characterized by the rigidity and the incompressibility. These three quantities cannot be derived from the two velocities, but estimates can be arrived at when information from various other sources is taken into account. Bullen finds that the density increases in the mantle from about 3·3 g/cm^3 just below the Mohorovičić discontinuity to about 5·5 g/cm^3 at the bottom of the mantle. It then jumps to about 9·5 g/cm^3 and increases to 11·5 g/cm^3 at the bottom of the outer core. In the inner core there is a strong increase. The rigidity that represents the resistance to shearing stress increases in the mantle, until at the bottom it is nearly four times that of ordinary steel. In the outer core the rigidity is quite small, and this is what we mean when we say that the core is fluid. On the other hand, the incompressibility or the

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resistance to pressure does not change materially at the boundary of the core. The pressure when evaluated was found to have reached about $1\frac{1}{3}$ million atmospheres at the bottom of the mantle and about 4 million atmospheres at the centre of the Earth. Following a long line of argument, Bullen arrives at the conclusion that the inner core is likely to be solid.

The composition of the continental crust varies a great deal from one region to another. Granite is one of its main constituents, whereas this material is absent under the deep oceans, where the crust is much thinner. The upper mantle is believed to consist of ultrabasic rock such as olivine. A transition is likely to take place, perhaps from one form of olivine to another, in the region where the seismic velocities increase more strongly than elsewhere, this region beginning at a depth of a few hundred kilometres. It has for a long time been believed that the core consists of iron and nickel, but recent investigations have led to the conclusion that the outer core possibly consists of material not much different from that of the mantle but transformed under the prevailing high pressure. The inner core is still believed to consist chiefly of iron and nickel.

BIBLIOGRAPHY

OLDHAM, R. D. *Quart. J. geol. Soc. Lond.*, **62**, 456, 1906.

MOHOROVIČIĆ, A. *Jb. met. Obs. Zagreb*, **9**, 1, 1910.

GUTENBERG, B. *Nachr. Ges. Wiss. Göttingen, Math.-Phys. Kl.*, 1, 1914.

GUTENBERG, B. and RICHTER, C. F. *Beitr. Geophys.*, **43**, 56, 1934.

JEFFREYS, H. and BULLEN, K. E. *Publ. Bur. Centr. Séism. Internat.*, A 11, 1, 1935.

JEFFREYS, H. *Ibid.*, A 14, 1, 1936.

Book reviews

OPERATIONAL RESEARCH

Proceedings of the First International Conference on Operational Research, Oxford, 1957, *edited by M. Davies, R. T. Eddison, and T. Page. Pp. viii+526. The English Universities Press Ltd, London.* 1958. 50*s. net.*

Operational research is now generally regarded as sufficiently important and extensive to be looked upon as a subject existing in its own right. It has its own methods and fields of application, the former including some new branches of applied mathematics.

The first international conference on the subject was attended by 250 delegates from 21 countries. About 28 papers were presented, covering the functions and philosophy of operational research and the methods and applications. Some of the papers, such as that by P. Naor on machine interference and that by T. C. Koopmans on water storage, show the high degree of sophistication reached in the mathematical treatment; others, such as that by J. Stringer and K. B. Haley on a large-scale transportation problem, indicate a delicate blending of mathematical formulation and numerical analysis, including the use of a special analogue computer. The paper by J. C. R. Clapham and H. D. Dunn on communication in collieries is a very good example of the highly practical type of operational research, carried out in this case by the National Coal Board. Another paper of this type is that by J. R. Manning on tolerances in fitting shoes.

Accounts are given of the state of operational research (in 1957) in 16 countries. These reveal that it is now conducted on a world-wide scale. No country which seeks efficiency can afford to neglect operational research.

L. S. GODDARD

PAPER CHROMATOGRAPHY

Chromatographic Techniques: Clinical and Biochemical Applications, *edited by I. Smith. Pp. xiii+309. William Heinemann Ltd, London.* 1958. 45*s. net.*

This book deals almost entirely with the techniques of paper chromatography. The title might therefore be open to criticism, suggesting as it does a wider approach to the subject than in fact is presented. No reservations, however, need be made about the contents. Under the editorship of Dr Smith, who himself makes several important contributions, nine specialists deal with the techniques and applications of paper chromatography in their particular fields. In the chapters dealing with amino-compounds, sugars, phenolic acids, and steroids there are, in addition, separate sections dealing with clinical interpretations. There is a final chapter of model experiments for students. This is essentially a practical book and, based as it is on the wide experience of Dr Smith and his co-authors, it will be invaluable to the laboratory worker wishing to apply paper chromatography to his problems for the first time. The detailed practical instructions given will often have been sought in vain in the original literature, as pressure on space seldom permits authors to give more than the bare outline of techniques. The more experienced worker will find much unpublished information on reagents and solvents, together with complete details for their use. The bibliography is sufficiently detailed to enable those wishing to obtain a broader view of chromatography to do so. A. J. WOIWOD

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PRACTICAL ORGANIC CHEMISTRY

Elementary Practical Organic Chemistry, *by A. I. Vogel. Pp. xxviii+890. Longmans, Green & Co. Ltd, London.* 1958. 45*s. net.*

This volume consists of three parts, each of which has already been published separately. Part I is a manual of preparative organic chemistry using small quantities (1–25 g) of organic chemicals and employing small-scale apparatus, some of which has been specially designed by the author. Part II deals with qualitative analysis and includes tables of derivatives which are much more comprehensive than is usual in elementary textbooks. Part III describes methods of quantitative organic analysis, mainly based on the determination of functional groups by a variety of old and new methods; it includes the determination of nitrogen, halogens, and sulphur. For many students Part III will be largely or wholly unnecessary and its inclusion in an elementary textbook is of debatable value, but for those who need all three parts the triad represents a saving of 18s.

The whole book is excellently produced and very lucidly written, as well as being illustrated with a large number of line drawings. All the procedures have been tested in the author's laboratory and are described in complete detail. Whether purchased singly or together as in the present volume, all three parts can be strongly recommended. J. F. W. McOMIE

ORGANIC CHEMISTRY

Lehrbuch der organischen Chemie (*fifth edition*), *by H. Beyer. Pp. xvi+690. S. Hirzel Verlag, Leipzig.* 1958. *DM* 22.50 *net.*

This is a partly revised, but not enlarged, version of the 3rd/4th edition (1955). The whole of organic chemistry is dealt with in 647 pages.

After a 29-page introduction on purification, analysis, and the theory of chemical bonding, 268 pages are devoted to aliphatic chemistry, 8 to cycloparaffins, 140 to aromatic compounds, 41 to hydroaromatics, terpenes and steroids, 114 to heterocyclic chemistry, and 46 to proteins and enzymes. There is a good index of 43 pages, and the references are commendably up to date, in some cases to late 1957.

The discussion of reaction mechanisms is begun early and continued throughout the book; the symbols used follow English practice fairly closely. Petroleum, plastics, stereochemistry, coenzymes, the citric acid cycle, terpenes, steroids, and alkaloids are briefly but competently dealt with. Only four pages are given to carotenoids—discussion of degradations, syntheses, and even colour of the important compounds being omitted. There is a confusing lack of uniformity in the formulae of ring compounds: to note only one example, the carbon atoms are omitted from the naphthaquinone formulae on page 431, but anthraquinone derivatives (pages 436–441) have exaggerated C=O groups placed with the C well outside the ring.

The general effect of the book is to give the reader a fascinating picture of the range of organic chemistry, though the treatment of most topics must be brief in a volume of this size. The printing is excellent, and the paper is a great improvement on that used in the previous edition. One result is that the thickness of the volume has been reduced to 1¾ in. As the author's style is clear, this book should provide honours students with stimulating views of the subject. J. C. SMITH

ELECTRONIC THEORIES OF ORGANIC CHEMISTRY

An Introduction to Electronic Theories of Organic Chemistry, *by G. I. Brown. Pp. viii+209. Longmans, Green & Co. Ltd, London.* 1958. 15*s. net.*

Within a comparatively short space of time the nature of organic chemistry has undergone a revolutionary change, owing to the application of electronic theories to problems of constitution and reaction. So fundamental is the change that even students of the elements of organic chemistry find it necessary to acquire at least a qualitative familiarity with the principal features of the theories concerned. Mr Brown's book is a notably successful effort to provide this information in an easily intelligible way.

After a concise, and very useful historical introduction to the development of ideas on the general structure of organic compounds, a chapter is devoted to the nature of the atom; this is perhaps unduly compressed and would serve better as a recapitulation for more experienced students than as pabulum for the beginner. Such criticism does not apply to the rest of the book, which takes the reader by logical stages from the formation of interatomic bonds and the nature of covalency to the structure of benzene, substitution in the benzene ring, and reaction mechanisms. Hydrogen bonding receives a short but sufficient chapter, in which the effect of this bonding upon the basic strength and solubilities of amines, and upon association and chelation, is described and explained. The book concludes with a bibliography and a full index. It should be of value not only to science specialists at school but to undergraduates and to those mature organic chemists who have occasion for a rapid survey of electronic theory in relation to aspects of their chosen field. E. J. HOLMYARD

MODERN ORGANIC CHEMISTRY

A Modern Approach to Organic Chemistry, *by J. Packer and J. Vaughan. Pp. x+973. Oxford University Press, London.* 1958. 84*s. net.*

The study of reaction mechanisms in the field of organic chemistry over the past thirty years has proved so fruitful that as a result our understanding and practice of the subject have been transformed. We have been slow in Britain to incorporate into our undergraduate courses the principles that have resulted, and this is paralleled by a dearth of elementary textbooks which feature mechanistic concepts as an integral part of exposition. The authors of this book have set out to remedy this situation and within their self-imposed limits have made a useful contribution. Theory is introduced (albeit with a distinct English emphasis) as the need for its understanding arises. Thus structural theory in terms of atomic and molecular orbitals is presented in an introductory chapter; the concept of resonance first appears in the discussion of conjugated di-olefines; homolysis and heterolysis are defined before the addition reactions of alkenes; substitution and elimination reactions fit into the chapter on alkyl halides. Wherever possible the authors have included reaction mechanisms; where these are merely speculative this is generally indicated. Just over one-half of the book is devoted to aliphatic, the remainder to aromatic and heterocyclic chemistry (only 45 pages to the last). For a book aiming to present 'a modern approach to organic chemistry' there are notable omissions: steric factors in reaction mechanisms and conformational analysis receive only the briefest mention; natural products, including proteins, vitamins, alkaloids, steroids, and terpenoids, and the concept of biogenesis are omitted entirely. The authors have taken a somewhat limited

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view of their field, and it will not be surprising if at its price this book does not commend itself to students. It should nevertheless do something to invigorate our teaching methods, and in this context the authors merit our gratitude for taking a step in the right direction.

The type and layout are on the whole admirable. The completely indiscriminate use of the cyclohexane and Kekulé symbols to represent aromatic rings is, however, wholly deplorable. K. H. OVERTON

THE IONOSPHERE

The Ionosphere, *by K. Rawer. Pp.* 202. *Crosby Lockwood & Son Ltd, London.* 1958. 42*s. net.*

This book, written five years ago, will already be known in its German edition to many workers on the ionosphere. An English translation is very welcome.

The subject is introduced by a description of the method of echo sounding and of the propagation of radio waves in an ionized medium. Other methods of investigating the upper atmosphere are described, including the use of rockets, but not, of course, artificial satellites. Theories of the formation of the ionized layers are explained and the regular and irregular changes of the ionosphere are discussed. A final chapter deals with the application of the results to practical radio communication.

The book will be most useful to research workers and to radio engineers interested in the more scientific aspects of research on the upper atmosphere. The extensive bibliography is very valuable. The general reader will not find the book easy to read, though some sections are of general interest.

It is unfortunate that the clarity of the author's writing has not been preserved in the English translation. The text gives the impression of having been translated word for word with little attempt to use idiomatic English. Even recognized technical terms are not always correctly translated. As an example, the term 'space wave' is used where 'sky wave' would have been correct. Experienced workers will no doubt be able to guess the meaning in most cases. A student new to the subject would, however, pick up some very unfamiliar terms if he confined his reading to this book. There are also a number of misprints.

B. H. BRIGGS

EVOLUTION

The Evolution of Development, *by J. T. Bonner. Pp. vii* + 103. *Cambridge University Press, London.* 1958. 17*s.* 6*d. net.*

In the smallest unicellular organisms the young and adult differ only in size; there are no embryological processes as we know them in higher animals. These processes have apparently evolved independently in many different lines as multicellular organisms appeared. The existing simple multicellular forms show various types of development, and from study of these the author tries to deduce the advantage for survival that is provided by having adults that differ from the young. For example, the slime moulds have no processes of meiosis and fertilization, but their genetic systems allow, in their own special way, for mutation and dispersal of the variants. Evolutionary adaptational changes can thus proceed, but without any of the advantages of recombination that are provided by sexual processes. The mechanism of 'development' in these organisms does not follow cleavage of a fertilized egg, but results from the coming together of numerous separate amoeboid cells. Thus the race achieves the advantages both of reproduction by division into small bodies and of large sizes and differentiated parts in the adult stage.

The author pursues most ingeniously the idea that what is involved is a 'package of variations' and that in order for these to be effectively displayed, a process of development involving proper spacing of the parts under the control of a communication system of polarities and gradients is necessary.

With this theme many examples of reproductive processes in lower organisms are discussed. Finally, there is a sudden and surprising jump to the subject of communication between higher animals as shown by the ethological school of Tinbergen and Lorenz. It is not clear why the author should have chosen to call attention to these rather than to the many other examples of communication that are involved in the physiology and behaviour of higher organisms. The various types of communication can only be made to illuminate each other, however, by the use of a common and exact terminology, such as that of information theory, which, quaintly enough, is not even mentioned in the book. J. Z. YOUNG

PROTEIN STRUCTURE

Symposium on Protein Structure, *edited by A. Neuberger. Pp.* 351. *Methuen & Co. Ltd, London; John Wiley & Sons Inc., New York.* 1958. 45*s. net.*

Those who attended the I.U.P.A.C. Symposium on Protein Structure held in Paris in 1957 will recognize in this book a faithful record, not only of the proceedings, but of the spirit of this conference. The contributions, though necessarily limited in number, cover a wide field, yet reflect a theme which has been admirably brought out by Professor Neuberger's editing.

Discussions of individual proteins in this volume indicate acceptance of the concepts of primary, secondary, and tertiary structure as aids to elucidating their nature. The contributions of physical and organic chemists appear here in fruitful juxtaposition. Thus determination of the amino-acid sequence in enzymes (such as ribonuclease, discussed herein) seems a prerequisite for investigations of the chemistry of the active centre; the spatial configuration of the protein must also play a vital role, and here such methods as deuterium exchange and X-ray crystallography may provide an answer.

Discussion of such methods is provided in this book, but perhaps its main value is in the indications it gives of future progress in the field. 'Active fragments' of papain, pepsin, enolase, and bovine serum albumin are mentioned. 'Common amino-acid sequences' in the pituitary hormones and pancreatic proteinases are discussed. Progress in X-ray crystallography and in immunology is indicated, and papers on haemoglobin and tobacco mosaic virus suggest that protein microstructure may become, as Fraenkel-Conrat suggests, 'the Rosetta Stone of biochemical genetics'.

The paper, type, and diagrams are of unusually high quality for this type of book at this price. B. S. HARTLEY

ENZYMES

Enzymes, *by M. Dixon and E. C. Webb. Pp. xxxiii* + 782. *Longmans, Green & Co. Ltd, London.* 1958. 90*s. net.*

This is an encyclopaedic volume. The authors tabulate 659 enzyme reactions and produce photographs of all but fifteen of the enzymes that have been crystallized. This sets the tone for a systematic discussion and tabulation of most of the properties of the enzymes that any research worker may wish to look up. Ample references are made to

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original papers from which all this wealth of information has been extracted. Experimental techniques are, however, barely discussed, though some methods for enzyme purification and rate measurements are briefly summarized. Incidentally, it does seem odd to include some elementary kinetic algebra in the short chapter on enzyme techniques rather than in the chapter on enzyme kinetics. This has, however, obviously been done intentionally, and most of the criticisms which working enzymologists may level against one chapter or another are matters of opinion about the order or priority of space given to various subjects. The authors would not be human if there were not some errors and misleading statements as well as a little too much special pleading for some not very important hypotheses; but in general, on properties of isolated enzymes, the book can be used as a reliable guide. All biochemists must be grateful to the authors for producing such a comprehensive 'one-volume' treatise.

H. GUTFREUND

ENZYME CHEMISTRY

The Chemical Kinetics of Enzyme Action, *by K. J. Laidler. Pp. vi+419. Clarendon Press, Oxford.* 1958. 60*s. net.*

The publishers state on the dust-jacket that this book has been written both for biologists who are interested in enzyme mechanisms and for physical chemists who are interested in applying their methods to biological systems. It is the reviewer's opinion that the usefulness of this volume is much more restricted. It should really be called 'Kinetics for Biochemists' or 'Kinetics for Enzymologists', and as such should serve a good purpose. It is very doubtful whether a physical chemist wanting to apply his methods and ideas to biological problems would be well advised to use this book as a guide. It is clear that the author is well versed in the manipulation of kinetic equations and has a lucid way of presenting them, and it would perhaps have been better if Professor Laidler had restricted himself to this and, possibly, expanded his treatment to multi-enzyme systems and steady-state processes. Much of what he has to say about the biochemistry of enzymes and their reactions is presented better in other books, and many of the numerical data quoted are quite wrong.

Judging from the dates of the references quoted, the manuscript was completed two years before the book was published. That is a very long delay. The additional references to more recent work, given in an appendix, hardly make up for this. One would also have expected more careful proofreading of a book which has taken so long to produce. A change of the nomenclature for the Michaelis constant is not likely to be well received, and the inconsistency in nomenclature in this volume is unforgivable.

In spite of such criticisms, the book will prove valuable for reference.

H. GUTFREUND

TREE PHYSIOLOGY

The Physiology of Forest Trees, *edited by K. V. Thimann, assisted by W. B. Critchfield and M. H. Zimmermann. Pp. xvi+678. The Ronald Press Co., New York.* 1958. $12 *net.*

The Maria Moors Cabot Foundation is to be congratulated for arranging the symposium that brought together, at Harvard Forest, physiologists actively interested in work with forest trees. This book gives an account of the symposium.

As might be expected, the formal papers and discussion on many of the topics emphasized outstanding problems and pointed to the relevance of recent physiological work to scientific forestry. The book is divided into nine sections: water relations, photosynthesis, biochemistry, mineral nutrition, phloem transport, root growth, general growth phenomena, photoperiodism and thermoperiodism, and reproduction. Each section consists of a series of papers, some of which are reviews and others accounts of the methods or the results of particular studies. The most laudable characteristic of the symposium is the emphasis on the physiology of whole plants, for although much of the experimental work must be done on seedlings or parts of trees, each of the contributors attempted to assess the extent to which the results applied to the whole tree.

The book, which has been well edited and indexed, should be of interest both to plant physiologists and to working foresters. Some of the sections, for example those on photosynthesis and growth phenomena, review physiological knowledge so relevant to forestry that one wonders whether more frequent symposia or reviews of a similar nature might not prove valuable.

J. L. HARLEY

MOLLUSCAN MORPHOGENESIS

Morphogenesis: The Analysis of Molluscan Development, *by C. P. Raven. Pp. xii+311. Pergamon Press Ltd, London.* 1958. 70*s. net.*

In this book, which owes much to his own researches on development in the water snail *Limnaea stagnalis*, Professor Raven has brought together what is known of development in the Mollusca and shown how modern experimental studies are revealing the directive forces and the chemical interactions responsible for the sequence of structural change. The result is a much better balanced book than one concerned solely with experimental and chemical embryology; increase in depth more than offsets loss in breadth.

Dealing first with structure at all levels of complexity and then with what the experimentalists have achieved of causal analysis, Professor Raven starts with oogenesis, followed by chapters on maturation and fertilization, on cleavage, on gastrulation, on embryogenesis and on organogenesis. All are clearly presented and, especially in the earlier chapters, admirably illustrated. The comprehensive list of references gives, one is glad to note, full titles for all papers.

What matters in development are the genes in the nucleus, the particular assortment of material in the cytoplasm, and the effect of a cortical field considered to possess not only polarity but dorsoventral and transverse organization. Fascinating fields for further research unfold themselves. Workers on Mollusca, embryologists, general zoologists—all will profit from this book.

C. M. YONGE

ECOLOGY

Spiders, Scorpions, Centipedes and Mites. The Ecology and Natural History of Woodlice, 'Myriapods' and Arachnids, *by J. L. Cloudsley-Thompson. Pp. xiv+228. Pergamon Press Ltd, London.* 1958. 50*s. net.*

It is the subtitle rather than the title itself that reveals the aim of this excellent book. It is, in fact, concerned with the ecology—the life and the environment of—these animals and on this the author is authoritative: he has studied the animals he writes about, and for ecology this is of prime importance. The chapters are each concerned with one zoological group and are arranged in the same way, dealing with classification, distribution, method of movement, nutrition, vital cycles, and

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reproduction, all excellently illustrated with photographs and drawings. A rich collection of personal observations and acute comments conveyed in clear, concise prose deals with several major problems, notably of water exchange, and reveal the author as a thoughtful student of many facets of animal life. Even the specialist will find this book full of new information, and it should be read by anyone interested in animal life and adaptation. A systematic index and a glossary help the reader with the small number of necessary technical terms. M. VACHON

CARCINOGENESIS

British Medical Bulletin, Vol. XIV, No. 2, Causation of Cancer. *Pp.* 73–196. *The British Council, London.* 1958. 25*s. net.*

This number of B.M.B. on 'Causation of Cancer' comprises 21 reviews by 27 investigators from 16 centres in Britain and the Commonwealth. Appearing eleven years after a similar symposium in the same journal, it portrays the progress made during this period of rapid advances in the study of carcinogenesis.

Within the limitations of some 150 pages an interpretative rather than exhaustive analysis was clearly aimed at, with scant reference to work before 1947, and a selection of the most significant subsequent publications. While such a selective approach tends to permit personal bias, a commendable degree of objectivity was nevertheless maintained in most of the reviews. Furthermore, the interpretative treatment, with cautious speculations, helps to show the logical trend and purposefulness in each field—a quality not often detectable in more comprehensive reviews. This approach is a useful corrective to the dubious notion that science is best served by 'letting the facts speak for themselves'.

The choice of titles gives a clue to the fields in which progress has been most noteworthy. Thus, of the 21 reviews five are devoted to radiation—two in connection with leukaemogenesis; two deal with bladder carcinogenesis and another with the related subject of aromatic amines; two with co-carcinogenesis; one with endocrine carcinogenesis; and one with dynamic aspects of chemical carcinogenesis. Other reviews that represent progress of a less dramatic kind deal with the carcinogenicity of petroleum oil fractions, occupational carcinogenesis, experimental liver carcinogenesis, exogenous factors in lung tumours, and cholesterol carcinogenesis. The review on avian carcinogenesis does not record much recent progress; the one on the immunological basis of carcinogenesis is highly speculative; that on biological examination of chemical carcinogens has a decidedly practical slant. The introductory review on chemical carcinogens and their mode of action is broad in its conception, with perhaps an over-emphasis on chemical mechanisms.

The virtual absence of any discussion on viruses is rather surprising in a symposium on causation of cancer. Actually the title of the symposium is misleading, since the reviews concern themselves only with carcinogenesis.

This issue is dedicated to the memory of the late Sir Ernest Kennaway, who, more than any other, established the investigation of carcinogenesis on a truly scientific footing. I. BERENBLUM

INFECTIOUS DISEASES

Die Infektionskrankheiten des Menschen und ihre Erreger, *Vols. I and II, edited by A. Grumbach and W. Kikuth. Pp. xl*+840; 841–1702. *Georg Thieme Verlag, Stuttgart.* 1958. *DM* 198 *net.*

The authors have designed these volumes as a link between clinicians and biologists, to give clinicians some idea of the scope of modern developments in microbiology and parasitology and to give biologists some idea of the clinical picture. It is primarily a textbook of microbiology.

Basic general principles of the relationship between host and parasite, immunity, epidemiology, chemotherapy, and the morphology and physiology of bacteria, rickettsia, viruses, fungi, protozoa, and helminths are given in the general section of some 400 pages.

The special section deals with the various pathogenic micro-organisms individually. A brief note on the clinical condition caused by the parasite is followed by an extensive description of the morphology, physiology and biochemistry of the organism. A critical discussion of pathogenesis, epidemiology, diagnosis, specific therapy, and prophylaxis completes the picture. Extensive references to the literature, with titles of articles, are given in each section. These are up to date and cover English, American, and European publications. It is not a laboratory manual, and there are no photographic illustrations. It is, however, a valuable reference work in which the editors have succeeded in keeping a consistently high standard of clear expression and critical judgment in chapters by seventeen different authors. R. L. VOLLUM

HISTORY OF MAGIC AND SCIENCE

A History of Magic and Experimental Science, *Vols. VII and VIII:* The Seventeenth Century, *by Lynn Thorndike. Pp. x*+695 *and viii*+808. *Columbia University Press, New York; Oxford University Press, London.* 1958. 80*s. net per volume.*

Some thirty-five years ago the present writer had the privilege of reviewing the first two volumes of 'A History of Magic and Experimental Science'. It is therefore with particular pleasure that he welcomes this opportunity of congratulating Professor Lynn Thorndike upon the successful completion of his great work: the fruit of over half a century of writing and research.

All historians of science are familiar with the earlier volumes of this 'History', and rightly regard them as indispensable to the serious student of the subject. The concluding volumes merit the same high respect. As before, they are characterized by the author's astonishingly wide and deep knowledge of original sources, and one is inevitably reminded of Goldsmith's schoolmaster: 'and still the wonder grew, That one small head could carry all he knew'. But Thorndike's erudition sits lightly on his shoulders; his style is easy, and the narrative flows smoothly and compellingly. Comments, criticisms, and judgments are refreshingly individual and often enlivened by a dry, scholarly humour—as when it is suggested that Boyle's works appear so frequently in secondhand book catalogues either because no one will buy them or because those who do so find them unreadable and return them to the market.

By the seventeenth century the age of modern science was well under way. Yet it is easy to overestimate the extent and depth of the rational, scientific thought of the period: the occult arts and pseudo-sciences still flourished, often among men who made genuine scientific advances of the first order. Newton, for instance, was 'an unbridled addict' of alchemy; Boyle thought that tonsillitis could be cured by strangling a viper with 'divers sorts of threads' and then tying the threads about the neck of the patient; and Descartes believed that the wounds of a corpse bled at the

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approach of the murderer. To get an accurate picture of seventeenth-century science such aberrations must necessarily be taken into consideration. Not the least merit of Thorndike's work is that it helps us to view the progress of human thought and discovery in proper perspective.

E. J. HOLMYARD

BIOGRAPHY

D'Arcy Wentworth Thompson, the Scholar-naturalist, 1860–1948, *by Ruth D'Arcy Thompson. Pp. xi+244. Oxford University Press, London.* 1958. 25*s. net.*

At a time like this, when the problems of how to combat specialization and how to blend the humanities with science and technology are perennial subjects for academic pamphleteering, it is important to recollect that only ten years ago a man died who solved these problems in his own personality. He was D'Arcy Thompson, author of 'Growth and Form' (one of the few scientific books assured of immortality) and for over sixty years professor in Dundee and St Andrews. His daughter Ruth has put scientists in her debt by writing a sensitive and frank and altogether delightful life of her father. She succeeds remarkably in bringing to life his buoyant and boisterous personality, the restless power of his mind, and his overflowing kindness.

For D'Arcy Thompson there were no curtains of the mind between different subjects. He graduated in science. His Cambridge doctorate was in classics. His most important publications were in mathematics applied to biology. He made major contributions to the technology of the fishing industry. He was a master of the English language. Of course, he paid a price for this virtuosity. He published very little of what conventional scientists call original research. It is a little ironic to read letters from his teachers and friends urging him to do research for the sake of his reputation. Fortunately he disregarded their advice, and instead made a unique contribution to humanity.

The value of this admirable book is enhanced by a brief and masterly essay on D'Arcy Thompson's scientific work by Professor P. B. Medawar, whose own command of English would have earned D'Arcy Thompson's approval.

E. ASHBY

MEDICINE AT SEA

Medicine and the Navy 1200–1900, *by J. J. Keevil. Vol. II,* 1649–1714. *Pp. xii* +332. *E. & S. Livingstone Ltd, Edinburgh.* 1958. 40*s. net.*

The first volume of this work was reviewed in this journal in January 1958 (XVII, 53). The speedy appearance of the second volume, while most welcome in itself, is overshadowed by the fact that the author died, at a comparatively early age, before its publication. Surgeon Commander Keevil's knowledge of his subject was unrivalled, and it is much to be hoped that he left sufficient material for the work to be completed by another hand.

The present volume, covering the period of the Commonwealth, the Protectorate, and the early Stuarts, describes how the medical service of the Navy gradually developed into a corporate organization serving the specialized needs of medicine and surgery afloat. The process was a slow one and suffered many vicissitudes; sea-surgeons were badly paid, had no security of tenure, and alone among subordinate naval officers were not appointed by warrant. That matters eventually improved was largely due to the sheer force of circumstances. The almost continuous wars of the period brought appalling casualties, and the authorities were driven by necessity to make better and more ample provision for the sick and wounded. Sickness caused more deaths than did enemy action; thus in 1693 Sir Francis Wheler's naval expedition to Barbados lost 1300 sailors out of 2100 and 1800 soldiers out of 2400 from sickness, mainly from yellow fever.

Faced by such calamities, successive governments of the period slowly came to realize the importance of adequate medical staff, accommodation, equipment, and hospital ships for the Navy, and Commander Keevil tells the story of this belated and chequered amelioration. This volume, like the first, contains much of interest to scientists; it is admirably written, fully documented, and attractively illustrated.

E. J. HOLMYARD

A CENTURY OF FRENCH INVENTIONS

Brevets d'invention français, 1791–1902: Un siècle de progrès technique. *Pp.* 321. *Ministère de l'Industrie et du Commerce, Paris.* 1958.

This book is a guide to and catalogue of an exhibition opened at the *Institut National de la Propriété Industrielle*, Paris. The purpose of the exhibition is to illustrate the development of techniques during the course of the nineteenth century by descriptions given in patent grants. The number of such grants being very large, rigorous selection was inevitable, and about two hundred were finally chosen for exhibition. These come from a wide range of activities, including agriculture, foodstuffs, locomotion, textiles, steam and other engines, machine tools, building construction, public works, mines, metallurgy, firearms, telecommunication, legal metrology, electricity, ceramics and glassmaking, chemistry, heating, lighting, refrigeration, the graphic arts, photography, and music.

Besides a preface by Marcel Plaisant and a foreword by Guillaume Finniss there is an excellent general introduction by Maurice Daumas, of the *Conservatoire National des Arts et Métiers.* There are also short introductory passages to each of the various sections of the catalogue. In the exhibition, the patent documents are accompanied by relevant accessory material such as portraits, photographs, paintings, and models; these, too, are listed in the catalogue and considerably add to its interest. Among the subjects of the plates are a patent taken out by Pasteur in 1865 for a procedure relative to the conservation of wines, another (1877) by Friedel and Crafts for a method of preparing hydrocarbons, Thimonnier's sewing machine (1830), and a model of Héroult's electric furnace for the manufacture of aluminium.

The catalogue is of more than ephemeral value, and many scientists will be glad to have a copy on their shelves.

E. J. HOLMYARD

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Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

A Dictionary of Named Effects and Laws in Chemistry, Physics and Mathematics, *by D. W. G. Ballentyne and L. E. Q. Walker. Pp. v+205. Chapman and Hall Ltd, London.* 1958. 30*s. net.*

Scientists, especially those reading in a field not their own, who wish to identify a law, an effect, or a reaction associated with some particular scientist, are the intended users of this dictionary. The entries are arranged alphabetically, and historical and other background information is deliberately excluded.

The Physics of Rubber Elasticity (*second edition*), *by L. R. G. Treloar. Pp.* 342. *Oxford University Press, London.* 1958. 40*s. net.*

The main object of this book is to present the statistical theory of rubber elasticity and to show how this theory provides an explanation of the main physical properties of rubber-like materials. This edition has new material on swelling, crystallization, photoelasticity, and the phenomenological theory of large elastic deformations, including the application of the latter theory to engineering problems.

Tables of Interatomic Distances and Configuration in Molecules and Ions, *edited by L. E. Sutton. Pp.* 365. *The Chemical Society, London.* 1958. 42s. *net.*

A collection of results from electron diffraction studies of gases published by P. W. Allen and L. E. Sutton in 1949 was the origin of this book. It was decided that a more comprehensive work was needed rather than merely a second edition, and the book therefore contains all the useful data on interatomic distances and configuration in molecules and ions published before 1st January 1956.

The contents include a table of selected bond lengths giving the values believed to be known to ±0·02 Å or better; tables of inorganic and organic compounds, reference tables giving the literature reference and stating the method of measurement used; and a classified name index of organic compounds.

Higher Oxo Alcohols, *by L. F. Hatch. Pp. ix+120. John Wiley & Sons Inc., New York; Chapman and Hall Ltd, London.* 1958. 36*s. net.*

The oxo reaction is the reaction between an olefine, carbon monoxide and hydrogen to form a saturated aldehyde with one carbon more than the original olefine. This book reviews the patent literature on the oxo process—the complete reaction forming an alcohol from an olefine—and gives added information on the properties and utilization of the higher oxo alcohols.

Biological Laboratory Data, *by L. J. Hale. Pp. xx+132. Methuen & Co. Ltd, London; John Wiley & Sons Inc., New York.* 1958. 15*s. net.*

The aim of this book is to provide the mathematical, physical, and chemical data frequently required by the research biologist, together with a selection of recipes. The data include tables, algebraic and geometrical formulae, and information on vapour pressure, *p*H, and buffers, and recipes are given for saline media, salt water, and culture media; the histological section includes information on staining. There are references to further sources of more specialized information.

Advances in Enzymology, *Vol. XX, edited by F. F. Nord. Pp. vii+488. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London.* 1958. $12.50 *net.*

There are twenty essays in this volume, on subjects which include the possible relation between optical activity and ageing, the role of imidazole in biological systems, the enzymology of the plastids, and antibiotics and plant diseases. The book includes a cumulative index to volumes I–XX, as well as separate indexes to volume XX itself.

Molluscs, *by J. E. Morton. Pp.* 232. *Hutchinson & Co. (Publishers) Ltd, London.* 1958. 10*s.* 6*d. net.*

The author of this book aims to provide an introduction to the form and functions of the *Mollusca* in the light of present-day studies. It discusses the basic structure and evolutionary pattern of the six classes of living molluscs; final chapters deal with the classification and evolutionary radiation of the Gastropoda, Lamellibranchia, and Cephalopoda. The volume is one of the Hutchinson University Library.

The Circulation of the Blood, *by William Harvey. Pp. xxiii+184. Blackwell Scientific Publications Ltd, Oxford.* 1958. 22*s.* 6*d. net.*

Two anatomical essays, addressed to Jean Riolan, jr., on the circulation of the blood, written in reply to a work of Riolan taking a modified Galenist view, are published in this book, together with nine letters by Harvey. The essays and letters are given in the original Latin, together with a slightly annotated English translation by K. J. Franklin, who has also added a short biography.

Electric Technology, U.S.S.R. *Chairman of the Editorial Board, Philip Sporn. Vol. I. Pp.* 179. *Pergamon Press, London.* 1958. *Subscription £20 p.a. for four volumes.*

The Pergamon Institute publishes this journal, which consists of selected papers from Электричество (*Elektrichestvo*), the Russian journal covering electrical engineering except for the fields of radio communication and electronics. This number contains translations of sixteen selected papers from Nos. 1–4, 1957, of *Elektrichestvo.*

Statistical Theory of Irreversible Processes, *by R. Eisenschitz. Pp. viii+83. Clarendon Press; Oxford University Press, London.* 1958, 8*s.* 6*d. net.*

This book presents previously unconnected topics in the microphysical theories of macroscopic irreversible processes as special instances of the general theory which has only recently gained a sound dynamical foundation. The assumptions of the theory are clarified and attached to the macroscopic phenomena, discarding arbitrary speculation, and mathematical deductions are supplemented by verbal reasoning. Most of the results are deduced from classical rather than quantal dynamics.

Sound pulses, *by F. G. Friedlander. Pp. xi+202. Cambridge University Press, London.* 1958. 40*s. net.*

This monograph deals with aperiodic disturbances with clearly defined fronts, using a treatment based on the theory of linear differential equations of hyperbolic type. The subjects covered include the equations of motion, wavefronts and characteristics, geometrical acoustics, and the diffraction of a pulse by wedges, spheres, and other objects.

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Notes on contributors

D. J. MALAN,
D.Sc., F.R.S.S.Af.,

Was born in South Africa in 1905. He was educated at the University of Cape Town and at the Sorbonne, Paris. After lecturing in physics at the Universities of Cape Town and the Witwatersrand he joined the staff of the Bernard Price Institute of Geophysical Research in 1946 as a full-time research worker on atmospheric electricity. He has been associated with B. F. J. Schonland in research on lightning since 1931 and has published many papers on the subject.

W. A. SMEATON,
Ph.D., A.R.C.S., F.R.I.C.,

Was educated at Harrow County School, Morrison's Academy, Crieff, and Imperial College, London. He graduated in chemistry in 1945, and from 1946 to 1958 taught inorganic chemistry at Northern Polytechnic, London. Since 1952 he has also carried out research in the history of science at University College, London, and he is now a research fellow in the *Institut d'Histoire des Sciences et des Techniques* of the University of Paris. He has worked mainly on French science of the late eighteenth century.

J. A. STEERS,
M.A.,

Was born in 1899 at Bedford, and was educated privately and at St Catharine's College, Cambridge. He spent about two years as a schoolmaster, and in 1922 he returned to Cambridge as a student demonstrator, was elected a Fellow of St Catharine's in 1925, and later held the offices of Tutor, Dean, and President. In the university he succeeded Professor Debenham in the chair of geography in 1949. He has been particularly interested in coastal physiography in Great Britain and has also studied tropical coasts in Queensland and Jamaica. This year he is Visiting Professor at Berkeley Campus, University of California.

E. T. HALL,
M.A., D.Phil.,

Was born in 1924 and was educated at Eton and New College, Oxford, where he graduated in chemistry in 1953. He later took his doctorate in physics at the Clarendon Laboratory, where he worked on primary and secondary X-ray fluorescence. He has been Director of the Archaeological Research Laboratory in Oxford since it was established in 1954–55. During the past four years he has directed research into the development of special techniques in X-ray, optical emission and γ-ray spectroscopy, magnetic dating, and proton magnetometry for the particular purpose of solving archaeological problems.

SIR HAROLD SPENCER JONES,
K.B.E., M.A., Sc.D., D.Phil., Ll.D., F.R.S., F.R.S.E.,

Held the position of Astronomer Royal from 1933 to 1955. He was born in London in 1890 and was educated at Latymer Upper School, Hammersmith, and Jesus College, Cambridge. From 1923 to 1933 he held the post of His Majesty's Astronomer at the Cape of Good Hope. He was knighted in 1943. He has received the Royal Medal of the Royal Society, the Gold Medal of the Royal Astronomical Society, the Janssen Medal of the Astronomical Society of France, the Bruce Gold Medal of the Astronomical Society of the Pacific, and the Gold Medal of the British Horological Institute. He is an Honorary Fellow of Jesus College, Cambridge, a past president of the Royal Astronomical Society, of the British Astronomical Association, of the Institute of Navigation, and of the International Astronomical Union. He is president of the British Horological Institute. He is a foreign member of many national academies and an honorary member of many Dominion and foreign astronomical societies. Was Secretary General of the International Council of Scientific Unions, 1956–58.

F. C. FRASER,
D.Sc., F.L.S.,

Was born in 1903 at Dingwall, Scotland, and was educated there and at Glasgow University, where he gained the degrees of B.Sc. in 1924 and D.Sc. in 1936. After a year's post-graduate demonstrating in the Geology Department he joined the Discovery Expedition (later Discovery Investigations) and served as a zoologist successively in the Royal Research ships *William Scoresby*, *Discovery*, and *Discovery II* in expeditions to the sub-Antarctic and Antarctic concerned with biology in relation to whales. He was appointed Assistant Keeper in the Department of Zoology, British Museum (Natural History), in 1933. He is the author of papers on krill (whale food) and, in some cases jointly with P. E. Purves, on various aspects of cetacean taxonomy and anatomy, and with J. R. Norman of the book 'Giant Fishes, Whales, and Dolphins'.

P. E. PURVES

Was born in Edinburgh in 1915 and was educated at Whitley Grammar School. He was appointed to the staff of the British Museum (Natural History) in 1934 after studying natural sciences at Chelsea Polytechnic and Birkbeck College. During World War II he was commissioned in the Royal Artillery. He is the author of a number of papers on the application of plastics to museum and anatomical technology. He is the co-author with F. C. Fraser of papers on the anatomy and physiology of whales and the originator of the 'ear plug' method of age determination for the baleen whales, a method applicable to mature and immature specimens of both sexes.

I. LEHMANN,
Cand. Mag., Mag. Scient., A.R.A.S.,

Was born in Copenhagen in 1888. She took a degree (Cand. Mag.) in mathematics in 1920 and another (Mag. Scient.) in geodesy in 1928, both in the University of Copenhagen, and studied mathematics at Newnham College, Cambridge, from 1910 to 1911. From 1923 to 1927 she was an assistant to the professor of actuarial mathematics in the University of Copenhagen and an assistant to the Director of *Gradmaalingen*, Copenhagen, 1925–28. She was head of the Seismological Department of the Danish Geodetic Institute from 1928 to 1953 and as such was responsible for the operation of the seismological stations at Copenhagen, Scoresby-Sund, and Ivigtut. She has written a number of papers on seismology. She was one of the founders of the Danish Geophysical Society and its president from 1941 to 1944, and was active in the formation of the European Seismological Commission, 1951, and has been a member of it since then,

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The exploration of space

The great acceleration of scientific discovery and its application during the last two decades has created many problems, not least of which is to foresee and prepare for the far-reaching social consequences. That science is still widely regarded with suspicion, as being on balance more likely to destroy mankind than to bring great benefits, is in large measure due to failure to prepare the general public for developments that the responsible authorities should see to be imminent and inevitable. Neglect of this important aspect of policy is nowhere more serious than in relation to the exploration of space. The launching of the first artificial satellite by the Russians in October 1957 took the world almost entirely unawares, and provoked, beside much thoughtful comment, a flood of sensational and ill-informed speculation about its significance. Within less than two years progress in space exploration has been remarkable. Not only have more artificial satellites been launched, both by Russia and by the United States, but projectiles have been sent beyond the Moon to become permanent new planets. Preparations are known to be far advanced towards launching a man-carrying rocket into orbit round the Earth. It is clear that space exploration, long looked upon merely as the fantasy of writers of fiction, is on the verge of achievement. A new age of exploration is imminent whose full consequences cannot be foretold but can scarcely be less than those of the great voyages of discovery which for the first time made whole new continents open to western civilization.

That these exciting developments should widely be greeted not merely with apathy but with opposition is not altogether surprising, for there are many historical parallels. Many of the long sea voyages that shaped the modern pattern of civilization were looked upon in their day as acts of folly, and those who made them not only suffered much ill-rewarded hardship, or even punishment, but often had the greatest difficulty in obtaining the necessary support. Only when the enormous potential value of the new discoveries became apparent was the support forthcoming that would so much have eased the burden of the pioneers. Nevertheless, while fear of the unknown is a widely ingrained human quality, determination to conquer it regardless of the hazards is equally ingrained in a small minority. It is thanks to such determination in individuals that the principal territories of the earth have been explored, in spite of great difficulties and dangers, and the extent of the civilized world greatly extended. In this respect, however, the analogy between terrestrial exploration and that of space breaks down. When all else failed, terrestrial exploration could be sponsored by private groups and the support of governments could follow later. In the exploration of space precisely the reverse sequence of events seems certain. Because of its enormous initial cost, and of the stragetic considerations, the pioneer attempts must be government-sponsored if they are to be made at all. Later, perhaps, private enterprise may enter the field, just as it has done in the development of atomic power, originally the strict preserve of governments.

In considering the exploration of space, comparison with terrestrial exploration is inevitable, for no other can be made. Features common to both are certainly apparent. Against terrestrial exploration, for example, it was argued that it was pointless to seek remote and probably barren new lands, at the furthest limits of the then available means of transport, when there was still room for expansion and development at home. Similarly, it is now argued, often at a high policy level, that there is no point in venturing into space when so much research remains to be done in existing fields. A further reason for doubts about the value of space exploration is, of course, that it is linked with the unending struggle between nations to establish military supremacy. The launching of satellites is a by-product of the construction of long-range military missiles. This is universally known, and nobody supposes that the exploration of space springs in the first instance from a disinterested desire to extend scientific knowledge and better the lot of mankind. Nevertheless, the growing realization of the immense value of atomic power, despite the fact that it originally became available only through the manufacture of atomic bombs, encourages the hope that the origins of space exploration will in time be overlooked.

What are the merits of undertaking space exploration that can commend it to the governments of the great powers, which at present are the only bodies commanding sufficient resources to make it possible? First and foremost, of course, is the possibility of acquiring a wealth of valuable new scientific knowledge: the results achieved within a remarkably short time by the first satellites give convincing proof that this is not

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mere optimism. Hitherto we have been obliged to look into space through two narrow windows, corresponding to the wavelength of light and of radio waves. With the aid of instruments located beyond the confines of the atmosphere we can have a far less restricted view of the universe. It is impossible, in the nature of things, to predict what a venture into the unknown will bring forth, but there is ample historical evidence that in the long run pure research in a wide field yields high practical dividends. At least two major fields of applied science—meteorology and radio communication—are clearly likely to benefit enormously from increased knowledge not only of the upper atmosphere but of the newly discovered regions of high radiation intensity that lie above it. The vast economic value of accurate weather forecasting on a world-wide scale needs no emphasis: the possibility of achieving this, and perhaps also of gaining some measure of control over the weather, would alone justify very heavy capital expenditure. Ability to photograph weather conditions over vast areas would in itself be of great value, and already some success in this has been reported. Similarly, there would be great practical value in improving the quality and reliability of long-distance radio communication. These are well known to depend very much on solar conditions, and the recent photographing of the Sun's disk from a point far above the Earth's atmosphere is an indication of the way in which space exploration can advance the study of solar physics. Clearly, too, long-distance flying might be greatly speeded up if the greater part of the flight could be made above the atmosphere rather than through it: the development of the necessary materials and techniques could scarcely fail to be valuable for many other purposes.

Outer space provides experimental conditions not attainable in the laboratory, and much new knowledge in the field of astrophysics and atomic physics can certainly be expected to be gained. In the biological and biochemical fields the prospects are enormously interesting. It is hard to believe that life is unique to the Earth, and it may well be that even within the solar system—on Mars or Venus, for example—there exist living organisms, if only simple ones, whose vital processes are quite different from those of terrestrial plants and animals. That this is not an extravagant flight of fancy, but a serious consideration, is apparent from the fact that international agreement is already being sought on the organization of space flight so that the scientific results to be obtained will not be made uncertain by the unintentional introduction of biological material derived from the Earth.

Apart from such considerations, which follow fairly obviously from the trend of current achievements, space exploration clearly also has the possibility of opening up fields of knowledge whose very existence is at present unsuspected. Newton took a modest view of his own remarkable achievements: 'I seem to have been only like a boy, playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me.' Science has progressed remarkably since Newton's day, but none can doubt that the ocean still remains largely uncharted.

The exploration of space clearly ought to be an international venture, and the International Council of Scientific Unions has already performed a valuable service by establishing the International Committee on Space Research (Cospar), but, while there is already some degree of collaboration, it is evident that in present circumstances rivalry between nations is inevitable. It is to be expected, therefore, that there will be only limited publication of results achieved, and that only those nations that have themselves some worth-while contribution to make will benefit from the experience of others. In time this situation may change—as it has done in the field of atomic energy—but to wait for it to do so is to allow others to gain what is likely to prove a commanding lead. At present, space exploration is pre-eminently a Russian and American field. If other nations allow it to remain so, they run a grave risk of having no standing in what may prove one of the most fruitful fields of modern research. Manned flights into space clearly raise very great practical problems that are still far from being solved, but within the last two years it has been demonstrated beyond argument that much can be learned from instrument-carrying devices. The usefulness of such devices will increase as advances are made in instrumentation. Within this narrower, but still exceedingly important, field it is surely possible for research to be more truly international than it is at present. The recent announcement of a British programme for the design and construction of instruments to be carried in the satellites of other nations is a welcome first step in this direction. Further plans for an all-British effort in space exploration are under consideration, and it is very much to be hoped that they will soon develop and be put into effect.

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Galactic structure and the 21-centimetre microwave line

H. C. VAN DE HULST

It is a tribute to the spirit of the Dutch people that one of the most fruitful lines of modern astronomical research, the study of the 21-cm hydrogen line, began in Holland in 1944, when the country was suffering great privation and was almost completely cut off from the rest of the world. One of the distinguished pioneers in this field, who predicted from theoretical considerations the occurrence of the 21-cm hydrogen line, traces here the rapid progress that has been made since the war and discusses the light it throws on galactic structure.

The existence of electromagnetic waves was predicted by Clark Maxwell several years before they were produced experimentally by Hughes and by Hertz. The history of radio-astronomy shows a parallel, for the possibility of observing extra-terrestrial radio waves was considered more than thirty years before successful observations were made.

Marconi first sent a wireless signal over a distance of several kilometres in 1896. In the same year Wilsing and Scheiner attempted to receive radio signals from the Sun; their experiments were based on the correct assumption that the solar spectrum should extend through the infra-red into the radio domain.

The first detection of radio waves from outside the Earth came from an unexpected source. In 1930 Jansky detected radio waves emanating not from the Sun but from the Milky Way. Retrospectively this seems a startling discovery, but at the time astronomers paid no attention to it. Nearly ten years later, when more detailed results had been obtained by Reber, two astrophysicists, Henyey and Keenan, made a first attempt to explain this radiation. Their results were published in the 'Astrophysical Journal', and the astronomical world began gradually to appreciate the great possibilities of this field.

The expansion of radio-astronomy in the subsequent twenty years was tremendous. It has not remained an interesting annexe to astronomy, taken care of by a few specialists, but has penetrated deeply into many subjects of major importance in astronomy. In a few fields it has been found to be more useful than optical astronomy. The present situation is well illustrated by the fact that an up-to-date introductory course in general astronomy now has to refer to radio-astronomical findings in at least a dozen fields, such as the velocity and statistics of meteors, the temperatures of the planets, the solar corona, solar flares, gaseous nebulae and ionized regions of interstellar space, neutral clouds in interstellar space, the envelopes of supernovae, the structure and rotation of our Galaxy, the rotation and mass of other stellar systems (spiral nebulae), and the expanding universe.

The idea of investigating galactic structure by means of observations of neutral hydrogen originated in 1944, when Holland was cut off from normal communications with other countries and university life was disrupted. For all we in Holland knew, radio-astronomy was still exclusively an American affair, although actually Britain and Australia had already started their impressive work in this field. Oort, who had done much research on galactic structure, asked me to study, and to review at a colloquium, the theory behind Reber's observations. He also told me to look for spectral lines in this domain, as such lines would permit the measurement of velocities by the Doppler effect and thus give a very important clue for locating the origin of the radiation.

At this point we should recall the normal methods for determining distances in astronomy. The invariable predicament of the astronomer investigating galactic structure is that the distances of his objects are either unknown or poorly known. The most common types of stars in the Galaxy are distributed in a flat disk having a thickness of a few hundred parsecs and a radius of the order of 15 000 parsecs[1]. The Sun is located somewhere near the plane of symmetry of the disk, at 8000 parsecs from the centre. Looking from this isolated observing post, we can obtain reliable determinations of the distances of all stars nearer than 50

[1] 1 parsec $= 3{\cdot}08 \times 10^{18}$ cm $\approx$ 3 light-years.

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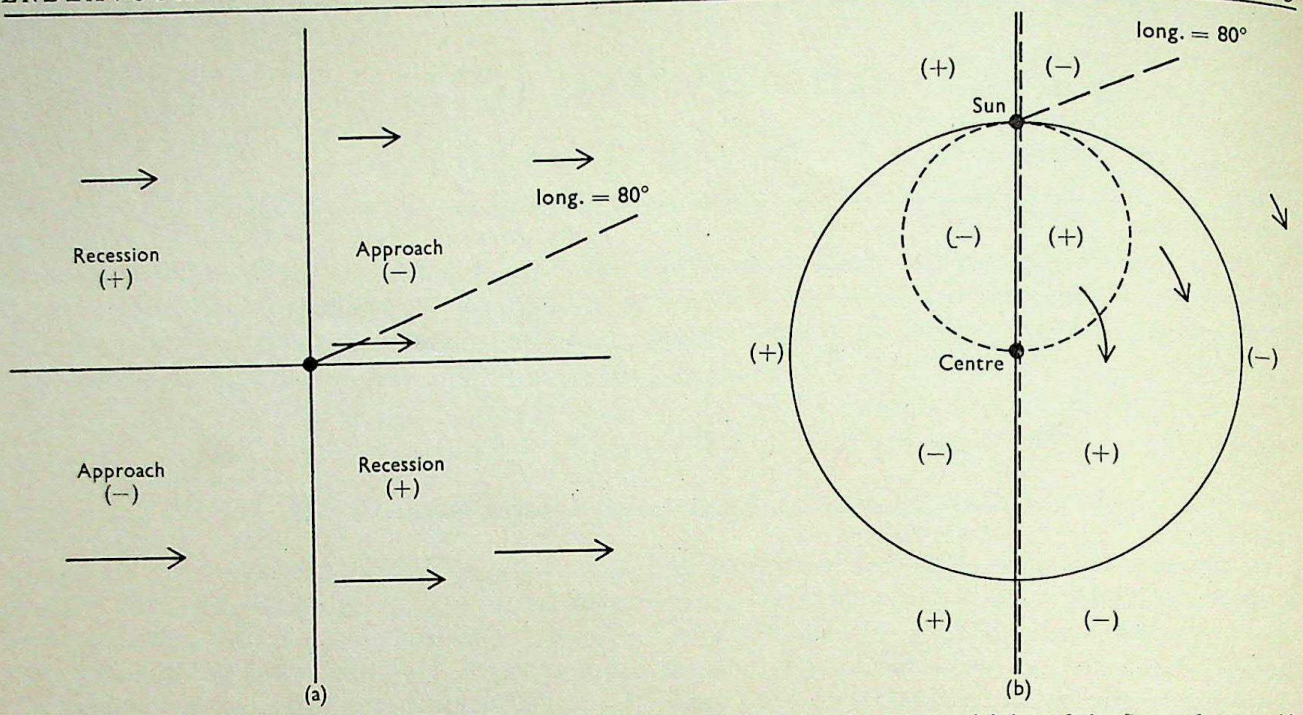

FIGURE 1 – *The phenomenon of differential galactic rotation.* (a) *The situation in the vicinity of the Sun: photographic and photoelectric observations do not penetrate beyond this region.* (b) *The situation over the entire galactic plane. This overall view is displayed only by the 21-cm line. In both diagrams + signs indicate systematic velocities of recession, − signs, systematic velocities of approach. The solid lines represent zero velocity. The distance estimate fails on the the broken line and circle, where the first-order change of velocity with distance is* 0.

parsecs by triangulation, based on the diameter of the Earth's annual orbit, but these stars are an almost negligible fraction of the entire Galaxy. However, observations of them provide the data for calibrating secondary distance standards that may be used farther out. Many of these are based on statistical studies of stellar motions.

A powerful method, applicable to stars more than 500 parsecs distant from us, is given by the observation of differential galactic rotation. With some exceptions, the stars in any local volume seem to move at random. Their speeds with respect to the centre of gravity of the group are of the order of 10 or 20 km/sec; the Sun is no exception and has a speed of 18 km/sec relative to the centre of gravity of all stars in our vicinity. However, on a galactic scale all these stars move together: the centre of gravity of the group describes a circular orbit around the centre of the Galaxy, each individual star moving in a somewhat excentric orbit. The actual speeds are high—the stars near the Sun have an orbital speed of 220 km/sec and an orbital period of 230 million years—although this can be detected only from the study of other groups of stars at considerable distances.

The angular velocity of the stars due to the rotation of the Galaxy decreases with distance from the centre, as is illustrated by the lengths of the arrows in figures 1*a* and 1*b*. If the broken line in figure 1*a* represents the direction of motion of the Sun, it is clear that the Sun will tend to overtake the stars in the top right quadrant and will approach them. Similarly the stars in the bottom left quadrant will tend to catch up the Sun and will also approach it. The stars in the other two quadrants, on the other hand, will be found to recede from the Sun. Observation confirms this. The relative speeds increase with the distance and can be measured by the Doppler effect. Hence they can be used for determining distances. A severe limitation of this method is that at distances of more than 2000 parsecs from the Sun optical observations of stars near the galactic plane become extremely difficult, because most objects are partially or completely obscured by interstellar absorption. Moreover, the linear approximation fails. The situation then obtaining is illustrated in figure 1*b*.

The same technique can be used in radio-astronomy. In the search for a suitable spectral line, one fine-spectrum possibility suggested itself. This is the line corresponding to a transition between the two levels into which the ground level of the hydrogen atom is split by the effect of hyperfine structure. In popular terms, the electron and the proton that make up the hydrogen atom may

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be looked upon as permanent magnets; the line is emitted when they switch from parallel to anti-parallel. The wavelength of this line, 21·2 cm, is convenient for modern techniques. In 1945, however, there were still technical difficulties in working at so short a wavelength, and, although the first attempts were made soon after that time, the actual detection of the line came only in 1951, with the almost simultaneous discoveries by Ewen in the United States, by Muller in Holland, and by Christiansen and Hindman in Australia. Since then there has been a steady period of data-collecting in Holland, in Australia, and in other countries.

THE TECHNIQUE OF OBSERVATION

In principle, the task of completely observing the 21-cm line is to make a map of the intensity as a function of three variables: the frequency (convertible into velocity) and two celestial co-ordinates. The equipment available for the purpose has improved strikingly during the last few years. Thus, to take further examples from Holland, there is an enormous difference between the equipment at Kootwijk in 1952 and that used at Dwingeloo in 1959. The apparatus first used was an old German radar mirror with an elliptical antenna beam of 2° × 3°. The telescope was cranked by hand, and laborious methods were used to check the frequency and keep the oscillators locked in. Now we have a well-designed 25-metre mirror with a round antenna beam of 0·57° diameter, and dial setting of the co-ordinates either for following a fixed position or for scans, and automatic frequency markers; a wide choice of time constants and bandwidths is now possible. An even more important improvement is in the sensitivity and stability of the receiver. A convenient unit in which to express the brightness of extended regions of the sky in radio-astronomy is the degree Kelvin (°K). A black body of the temperature thus expressed would have the same brightness, at a given frequency, as the actual object observed. When the 21-cm line was first observed, the maximum line intensity (about 100°K) was quite difficult to detect. For some years spurious fluctuations and jumps of the order of 5–10°K remained common. The zero of a modern receiver, however, drifts less than 1°K over a period of many days. The final accuracy seems to depend mainly on the bandwidth and on the time one can afford to average the receiver noise. In the present investigations on extra-galactic systems, where the intensity is lowest, an accuracy of 0·15°K is regularly attained.

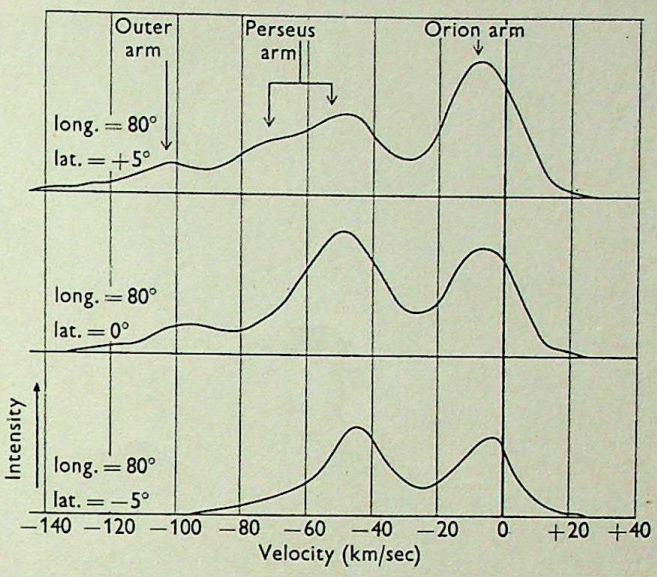

FIGURE 2 – *Line profiles for three points in Cassiopeia and Cepheus. Each profile is a plot of intensity against Doppler velocity. Their common longitude is 80° (broken line in figure 1). The middle point is in the galactic plane; the others have latitudes 5° above and below the galactic plane. Note different dependence on latitude in the three arms.*

The scans can be made in many ways, and the choice depends on practical considerations. Most often the telescope follows the daily motion of a point in the sky and a gradual scan in frequency is made. The result is a line profile, entirely comparable with the profile of an emission line in ordinary spectroscopy. An example is shown in figure 2. The vertical line at zero velocity indicates the undisplaced frequency: the spread in frequency is entirely due to the Doppler effect. This immediately suggests one method of analysis of these data, which we may call the standard method. If we assume that the random speeds of the atoms in their 'local' surroundings are zero, so that each atom follows the circular orbit around the galactic centre with an angular velocity appropriate to its distance from the centre, then the velocity may be translated directly into distance. Consequently, a maximum at a given frequency in a line profile corresponds to a concentration of hydrogen at a particular distance. These concentrations mark the spiral arms of our Galaxy.

MAPPING THE DISTRIBUTION OF ATOMIC HYDROGEN

The same method can be worked out quantitatively, because the lifetime of the upper level of the 21-cm line is known: the emission, a spontaneous transition of the atom, occurs on the average after 11 million years. In this way it is possible to convert the line intensity at each frequency into the

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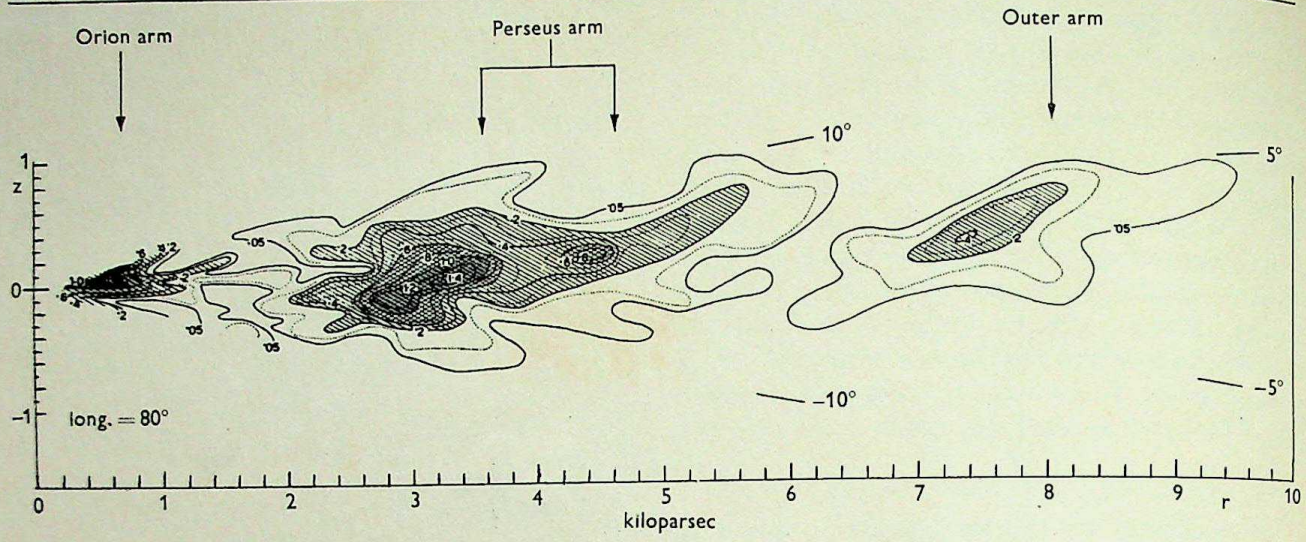

FIGURE 3 – *Cross-section perpendicular to the galactic plane. This shows isodensity contours of atomic hydrogen in a plane perpendicular to the galactic plane. The Sun (or Earth) is at the origin, r = distance from Sun along plane, z = distance from Sun perpendicular to plane. Heaviest shadings represent 2 atoms per cm³; the lowest contour represents 0·05 atom per cm³. Note here and in figure 2 that the Perseus arm is split and also that the outer arm lies above the galactic plane.*

density of hydrogen atoms at each point on the line of sight. The density varies from 2 atoms per cm³ to undetectably small values; the average for the galactic disk is about 0·7 atom per cm³.

There are, however, a number of problems that have to be solved and assumptions that have to be made before such a result can be obtained. It is necessary, for instance, to know the distance from the galactic centre to the Sun. Again, it is essential to know the rotational velocity of the stars at any given distance from the centre. Much of this information comes from optical astronomy. However, the radio measurements themselves can help in a surprising manner. When looking from our position (the Sun) in a direction inclined at an angle to the line joining us to the galactic centre we meet a point of maximum velocity at the point where the line of sight passes nearest to the centre. This maximum velocity directly gives the velocity of rotation at that point. In outward directions this method fails and a theoretical curve is used, based on an assumed distribution of mass in the Galaxy. For distances less than 3000 parsecs from the centre the method fails again, as will be seen from a later section.

The random speeds of the atoms cannot in fact be neglected. Not only do they have thermal velocities corresponding to a temperature of about 100°K, but observations show that interstellar gas clouds as a whole have random motions just as

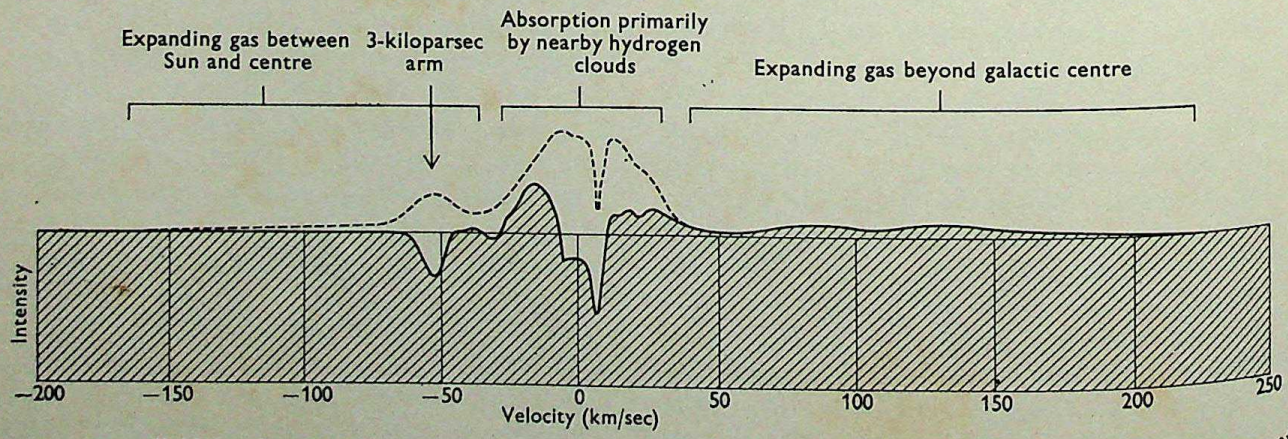

FIGURE 4 – *Evidence for expanding gas in the spectrum of the source at the galactic centre. The continuous spectrum of the source is indicated by the thin horizontal line. The hydrogen-line emission in the antenna beam, which was found by interpolation from the emission profiles at adjacent points on the sky, adds to this the intensity indicated by the broken line. The observed profile when the antenna is directed at the source is given by the solid curve. Hence the difference between the broken and solid curves shows the effect of absorption by hydrogen in front of the source.*

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stars do. The consequence is that the distance scale in the standard method is blurred. This blurring is similar in its effect to the blurring in the transverse co-ordinates due to the limited resolving power of the antenna. In addition, the line profiles show clear saturation effects in the peak intensities, so that a correction for self-absorption is needed, depending on the temperature of the gas.

The data can be collected and mapped after allowances have been made for all these complications. Figure 3 shows a typical map from the complete survey at longitude 80° of the volume between −10° and +10° galactic latitude, made with the Kootwijk telescope. Hydrogen densities have been computed from line profiles of lines of sight at intervals of $2\frac{1}{2}$° in latitude. The contours drawn on the basis of these data show the full distribution of atomic hydrogen in a plane perpendicular to the galactic plane. The plane is seen to cut several spiral arms and also some minor features. The major spiral arms have been given tentative names: in figure 3 the 'Orion arm' is not fully shown, because data at much higher latitude would be needed to cover it.

FIGURE 5 – *Artist's impression of the hydrogen spiral arms in our Galaxy. All relative concentrations of hydrogen atoms have been projected on the galactic plane.* ⊙ = *Sun,* + = *galactic centre. Sectors about the line joining the Sun and the galactic centre and opposite side have not been filled in.*

The nearer arms, or parts of them, can also be observed optically. In fact, the optical identification of the three nearest arms by Morgan and his associates in 1951 preceded the radio studies. It remains an open question whether the arms outlined by optical studies of young associations of stars, ionized gas regions, and Cepheid variables are identical with those found by observation of atomic hydrogen. The general agreement is good, but some exceptions have been noted.

About 150 maps like that shown in figure 3, obtained from observations at different longitudes, would give a complete three-dimensional picture of the hydrogen distribution in the galactic disk, subject to the limited resolving power of the $7\frac{1}{2}$-metre telescope used. The approximate linear sizes that could just be resolved were 150 parsecs in the transverse co-ordinates and 600 parsecs in the line of sight. These values are far too large to see the individual interstellar clouds, the diameters of which are of the order of 10 parsecs. The blurring is just right, however, to obtain a picture of the overall galactic structure without the complication of too much detail.

Such a three-dimensional map was ready in 1955. It was incomplete, firstly because the distance determination by the standard method fails on and near the dotted line and circle shown in figure 1, secondly because approximately one quadrant of the Milky Way never rises above the horizon in Holland. Two years later Australian workers had checked a large proportion of the northern measurements by a somewhat different method and had filled in the southern gap.

To arrive at an overall picture, Westerhout and

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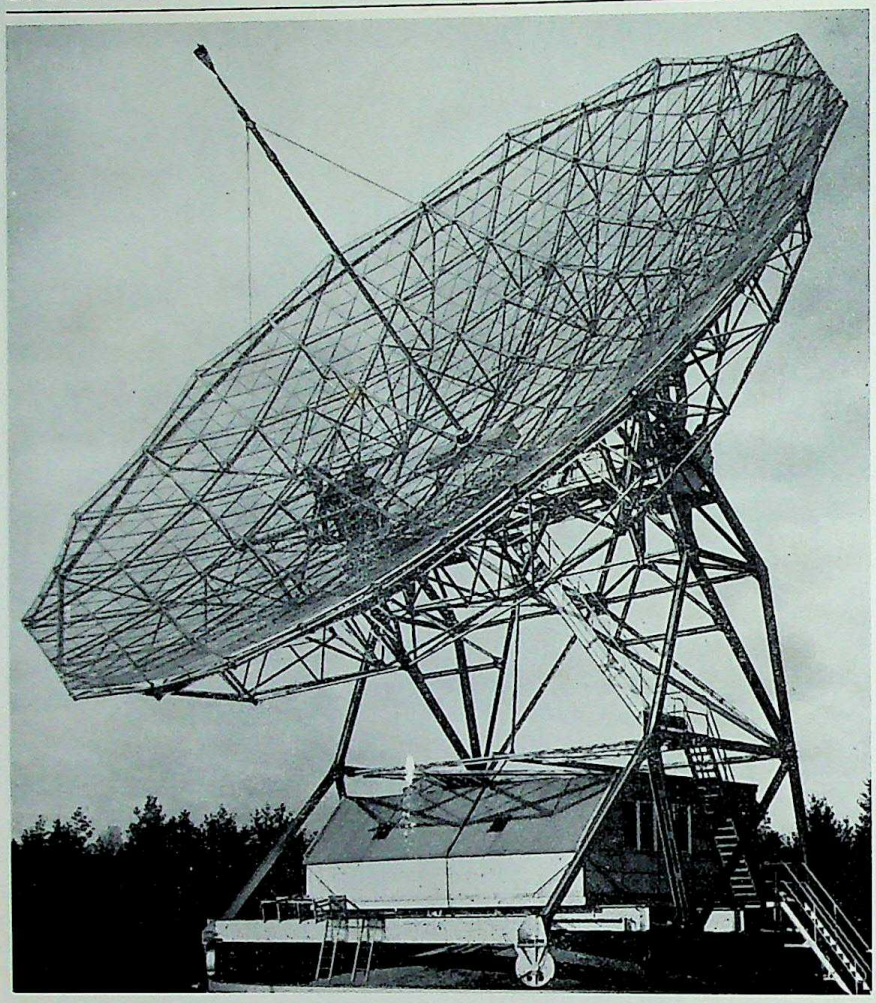

FIGURE 6 – *The 25-metre telescope at Dwingeloo.*

Kerr, with the Dutch and Australian data respectively, worked together for some months. The result can best be seen in the form of the 'artist's impression' reproduced in figure 5. This brings out both the strong and the weak features better than an isodensity contour map does. Although most of the hydrogen is confined to a narrow and surprisingly flat layer, the arms in the outer parts tend to deviate somewhat from this plane. The drawing reproduced in figure 5 accurately renders all well-established details in and near the plane. Thus it is the direct picture which a hypothetical observer in a different galaxy, fitted with eyes like giant radiotelescopes, would get of our galactic system. The details he sees are the 'spiral arms'.

It may rightly be asked, on inspecting this map, whether the term 'spiral arms' is not too fanciful. The purpose of making this drawing is, of course, to compare it with photographs of other spiral galaxies, formerly called spiral nebulae. We should, however, remember that the map is incomplete and may be distorted. There are two reasons for this. Firstly, local deviations from circular motion may suggest displacements in distance which are in fact displacements in velocity. Secondly, the sectors around the directions towards the centre and away from it have not been filled in because the method does not work there. These sectors should contain as much hydrogen as other parts of the Galaxy. Finally, the main question remains whether the spiral arms on photographs, outlined by bright stars and gaseous nebulae, may not differ from the hydrogen arms. This question cannot yet be answered, as very little is known, either from observations or from theory, about the origin and evolution of spiral arms.

In spite of these uncertainties it is possible to classify our Galaxy. Traditionally the spiral galaxies are subdivided in types Sa, Sb, and Sc. The Sa galaxies have a very large nucleus and a number of smooth spiral arms wound narrowly around it. The Sc galaxies have a small nucleus and usually two prominent patchy arms extending from it. Type Sb is intermediate. The radio map suggests strongly that our Galaxy is of the type Sb. Optical studies based on the stellar populations support this conclusion. The fact that many arms are nearly circular is not really disconcerting. The arms that do have a well-defined slope with respect to the tangential direction, especially in the outer part, all show that the sense of rotation is such that the arms are trailing.

FURTHER RESEARCH PROGRAMMES

In contrast to most of radio-astronomy, research on the 21-cm line has been relatively unexciting. The discovery was foreseen, the method of interpretation was foreseen, and even the result, a map showing spiral arms, was, in a sense, foreseen. As a result, our knowledge of galactic structure has made enormous strides in a few years, unhampered by baffling discoveries and serious misgivings about the interpretations. Nevertheless, it is a well known fact that we learn not from the predicted but from the unpredicted.

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Fortunately, after achieving a few more or less foreseen results, the time comes in any investigation for the genuine surprise or even for pure groping in the dark.

This time has already come for 21-cm line astronomy. After we had found, with a moderately powerful telescope, how right we were in our assumptions, others are now working, with more powerful equipment, trying to find how wrong we were. We shall briefly mention some of the directions in which research in this field has developed during the last years.

Firstly, attempts have been made in vain to detect at least one other line. A Russian team claimed at one time to have found the deuterium line at a wavelength of 93 cm, but the latest, very accurate, measurements by the Radar Research Establishment at Malvern, England, show this line to be still below the limit of detection.

Secondly, studies on the major part of the sky, outside the 20° belt along the Milky Way, have started. A fine overall survey was made by the Carnegie Institution in Washington, and regions of special interest, such as those in the constellation Orion, were studied at the Harvard Observatory and at Dwingeloo. The hope has almost vanished that such studies would tell us something about the huge halo surrounding the Galaxy. On the contrary, it is more likely that these regions of the sky tell us about only a very local part of the galactic disk. The possibility of resolving details of interstellar gas, with a size of 1 parsec, at a typical distance of 100 parsecs, is quite exciting. Probably the convenient working model of loose interstellar clouds with sizes of the order of 10 parsecs will have to be thoroughly revised.

Thirdly, there are about five sources of continuous radio emission strong enough to provide an absorption spectrum of the 21-cm line. Several of these sources have angular sizes of 5 minutes of arc or smaller. They have given radio-astronomers at Jodrell Bank, at the Naval Research Laboratory, Washington, and later those at Dwingeloo a chance to sample the hydrogen velocities in a very small solid angle while, incidentally, giving useful estimates of the distances of these sources.

Fourthly, other galaxies have been measured. The Radio-physics Laboratory, Sydney, completed a very fine investigation of the two Magellanic clouds several years ago. About half the masses of these nearer galaxies, which are small companions to our own, prove to consist of atomic hydrogen. Our own Galaxy, by contrast, contains about 2 per cent of atomic hydrogen. The well-known Andromeda nebula, an Sb system as our own appears to be, is about twice as large as our Galaxy and has only 1 per cent hydrogen. This nebula and half a dozen others have been investigated at Dwingeloo and at Harvard. The further step, to investigating even more remote objects in the universe by means of the 21-cm line, has not yet been made with certainty, although radio-astronomy in the wider sense has led to many reliable results in this field.

EXPANSION NEAR THE GALACTIC CENTRE

Finally, our own Galaxy provided a big surprise. It has become increasingly clear in the past two years that the hydrogen gas in the central parts of the galactic disk is expanding as well as rotating. This phenomenon, discovered at Dwingeloo and still almost entirely unexplained, is the most exciting result so far obtained in the whole of 21-cm radio-astronomy. All telescope time during the three hours of the day or night that the region near the galactic centre is above the Dwingeloo horizon has been reserved for many years to come for a further study of the phenomenon. It therefore seems fitting to use the remainder of this article to describe briefly the observations that have led to this discovery.

The observations that were aimed at finding the rotation law of the inner parts of the Galaxy met a difficulty in 1954. The method consisted of trying to find the maximum velocity in each direction of the galactic plane. This worked quite well at angles (longitude differences) of 25–65° from the direction of the centre. However, at longitudes less than 25° from the centre, no clear maximum velocity was found. Instead, the line profiles showed wings of low intensity with velocities reaching high values. Quite near the centre the wings were found at both positive and negative velocities, one of which is forbidden on the assumption of rotation. The clear inference was that the gas within 3000 parsecs from the centre had a motion quite different from simple rotation: we suspected turbulence.

However, the observations of these wings with the more powerful equipment at Dwingeloo at once revealed much detail, a result not in accordance with a general state of turbulence. Rather, a maximum occurring at a certain frequency at one longitude was usually found with a slightly displaced frequency at an adjacent longitude. This is just like the spiral arms found in the outer parts

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of the galactic system. But the 'forbidden' velocities remain, so that these arms cannot be located in space by the standard method.

The most prominent arm in this region can be followed over a 28° interval of longitude. By interpolation from adjacent longitudes, its velocity component in the line of sight, observed in the exact direction of the galactic centre, should be −53 km/sec. In this direction there is a strong source of continuous radio emission, which most probably is at the actual centre of the Galaxy. The continuous spectrum of this source makes it impossible to observe the 21-cm emission line in the normal manner. Instead we see a complicated spectrum, (figure 4) with absorption components (clouds of hydrogen atoms in the small solid angle subtended by the source), together with emission components (clouds of hydrogen atoms in the antenna beam but not covering the source). Early in 1957 it was found that a strong absorption line occurs exactly at −53 km/sec. This must be interpreted as representing the same spiral arm cutting between us and the galactic centre and having at that point a velocity component of 53 km/sec towards us. This is a velocity away from the centre—that is, an expansion. The transverse (rotational) velocity cannot be established exactly but is estimated from the observations at other longitudes to be 190 km/sec. This arm is probably at the fringe of the exceptional region and is called the '3-kiloparsec arm'.

It is significant that a few other, less prominent, arms having positive velocities also extend to the centre direction but are not found in absorption spectra. Hence they must be beyond the galactic centre, and their motion away from us is again an expansion away from the centre. When this had been found, it became really urgent to investigate systematically and with great accuracy the presence of possible absorption in the spectrum of the centre source at all Doppler displacements from −300 km/sec to +300 km/sec. The result, briefly explained in figure 4, is striking. No absorption at all is seen at the positive velocities. However, all negative velocities show a more or less prominent absorption effect. This shows that the phenomenon of expansion is not limited to a few spiral arms, but is common to all atomic hydrogen in this central part of the galactic system.

The explanation of this expansion seems almost impossible at the moment. One of the most puzzling facts is that the atomic hydrogen here, as elsewhere, is confined to a thin layer along the galactic plane. It is even a little thinner: about 100 parsecs. Any force giving rise to the expansion has to be highly directive along this plane. Another problem to be solved is where the hydrogen comes from. It seems difficult to postulate a source at the centre which is gradually becoming exhausted during the life of our Galaxy. More probably the material is sucked in from the galactic halo, where it has been present as a fully ionized, very tenuous gas. The general feeling is that somehow magnetic forces will prove to be responsible for all this, but more observation and more thought will be required before the situation can be clearly understood.

ACKNOWLEDGMENTS

So far as this paper describes investigations made in Holland, they have been made by the Netherlands' Foundation for Radio-astronomy, with the co-operation of the observatories at Leiden and at Groningen.

BIBLIOGRAPHY

Dealing with prediction, discovery, and physical theory of the 21-cm line:

VAN DE HULST, H. C. *Ned. Tijdschr. Natuurk.*, **11**, 201, 1945.

EWEN, H. I. and PURCELL, E. M.; MULLER, C. A. and OORT, J. H.; PAWSEY, J. L. *Nature, Lond.*, **168**, 356, 1951.

WILD, J. P., *Astrophys, J.*, **115**, 206, 1952.

FIELD, G. B. *Proc. I.R.E.*, **46**, 240, 1958.

Idem. Astrophys. J. (In press.)

Dealing with galactic structure and 21-cm maps:

OORT, J. H. *Astrophys. J.*, **116**, 237, 1952.

OORT, J. H., KERR, F. J., and WESTERHOUT, G. *Mon. Not. R. astr. Soc.*, **118**, 4, 1958.

VAN DE HULST, H. C. *Rev. Mod. Phys.*, **30**, 913, 1958.

Detailed publications on work at Kootwijk and Dwingeloo:

Bull. astr. Insts. Nethlds., **12**, No. 452, 117, 1954; **12**, No. 458, 211, 1954; **13**, No. 475, 151, 1957; **14**, No. 480, 1, 1957; **14**, No. 492. (In press.)

Symposium publications:

Reports on the Fifth Conference on Problems of Cosmogony (in Russian), Moscow, 1956.

International Astronomical Union Symposium No. 4 on 'Radio Astronomy'. H. C. van de Hulst (Editor), Cambridge University Press, London. 1957.

International Astronomical Union Symposium No. 5 on 'The Large-scale Structure of the Galactic System'. N. Roman (Editor), Cambridge University Press, London. 1958.

Onzième Conseil de Physique Solvay, 'La structure et l'évolution de l'univers'. Stoops, Brussels. 1958.

International Astronomical Union Symposium on 'Radio Astronomy'. R. N. Bracewell (Editor), Stanford University Press. Palo Alto. (In press.)

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The use of pituitary hormones in fish culture

JAMES W. ATZ and GRACE E. PICKFORD

Fish farming could be much more important than it is, particularly in areas of overpopulation and malnutrition. The problem has always been that many food-fish will not spawn in captivity. One possible solution lies in the use of pituitary extracts, which stimulate spawning. These have been found of value both for intensive fish cultivation and for solving the problems caused by damming the rivers in the Soviet Union in which the sturgeon breed. The experiments, results, and some applications are described in this article.

Fish have been kept in captivity since ancient times; as far back as 2000 B.C. the Sumerians maintained food-fish in ponds [1]. Fish domestication, however, has lagged behind that of mammals, birds, and insects. By 1000 A.D. only two species, the carp (*Cyprinus carpio*) and the goldfish (*Carassius auratus*), had been domesticated, both in China [2, 3]. The methods of culturing eggs and fry of freshwater food- and game-fish, first developed in Europe during the eighteenth and early nineteenth centuries, made it feasible to rear trout, pike, and similar species, but unwarranted enthusiasm regarding the effectiveness of stocking natural waters with young fish and the lack of economic incentive to raise these species to maturity in captivity impeded their domestication. Even today only a few species, notably the rainbow trout (*Salmo gairdneri*), can properly be said to be domesticated. In the Far East, the Siamese fighting fish (*Betta splendens*) has been selectively bred for combativeness during the past century [4], and more recently a number of other small tropical freshwater species have qualified as domestic animals by virtue of their continued propagation and selection in homes and hatcheries.

In contrast to these species, there are food-fish that have regularly been raised in ponds for many decades—some for centuries—that have not become domesticated, simply because they have refused to reproduce in captivity. Included among these are some of the most important edible species—the striped mullet (*Mugil cephalus*), the milkfish (*Chanos chanos*), and several carp-like species from India, China, and south-east Asia (such as *Ctenopharyngodon idellus*, *Aristichthys nobilis*, and *Hypophthalmichthys molitrix*). Since the fish farmer cannot breed these fishes, he is at the mercy of the available supply of fry spawned in the wild. Each year he must catch or buy fresh stock, and he is helpless if conditions are unpropitious for spawning in nature. Accurate figures are not available, but estimates of a decade ago indicate that more than a million acres of ponds were then employed in raising such fish, total production being of the order of half a million tons a year [5].

In a world where the human population is increasing at a rate of 25 million each year, and where half the people are already undernourished, no opportunity to improve the productivity of any important source of animal protein food can be neglected, especially if such food can be produced in the very regions where the greatest shortages of this vital component of man's diet occur.

One approach is suggested by the experiments of B. A. Houssay of Argentina, who in 1930 injected some small viviparous fish with pituitary glands recently removed from another species of fish, and brought about premature birth of the young [6]. Present-day concepts of the role of the pituitary gland (hypophysis) in the reproduction of vertebrates may be considered to have commenced three years before, when S. Aschheim and B. Zondek found that pituitary implants accelerated the sexual development and cycle of female mice, and P. E. Smith for the first time unequivocally demonstrated the effects of hypophysectomy and subsequent replacement therapy on the gonads of the laboratory rat [7]. Houssay, who has so often approached physiological problems from the comparative point of view, was not long in applying similar techniques to amphibians and fishes. His work soon came to the attention of R. von Ihering, Director of the *Comissão Técnica de Piscicultura do Nordeste*, at Ceará, Brazil. For years the chief problem in Brazilian fish culture had been to get native freshwater food-fish to spawn in captivity. Even when caught in a nearly ripe condition these species rarely, if ever, completed the maturation

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of their sex products, which degenerated instead. In nature, spawning precipitously follows the first storms of the rainy season, but the effective environmental stimuli could not be determined and thus duplicated in captivity. By 1934, after two to three years of experimentation, von Ihering and his collaborators had developed a successful technique for inducing pond-fish to spawn by injecting them with the pituitaries of other fish.

The pituitary gland is basically similar in all classes of vertebrates. It is a small body, located at the base of the brain (figure 1). Although small, it is a major controlling factor or 'master gland' in the animal's hormonal regulatory system. In a fish about one foot long the pituitary is about as large as the head of a match, and weighs from one to ten milligrams. In fish, as in other vertebrates, the pituitary is vitally concerned with the regulation of growth and of pigmentation, the adrenal cortex, the thyroid gland, and a number of less clearly understood functions, as well as with reproduction. Although the form and arrangement of the parts of the fish pituitary differ strikingly from those found in the higher vertebrates, the same essential elements are present, and, as far as known, the same types of cells are responsible for the production of the eight or more different hormones released by the gland in the course of its normal activities. Cyclical changes in the pituitary gland of fishes, correlated with the reproductive cycle, are striking (figure 2). They clearly show the increase and decrease in the cyanophil cells concerned with the production of gonad-stimulating hormones (gonadotropins), as well as showing the depletion of neurosecretory material associated with the release of these hormones.

As far as is known, all the hormones of the hypophysis are protein in character. Each kind of hormone appears to be basically of the same chemical structure, at least in the mammalian species that have been studied. It is clear, however, that there are important differences in the amino-acid sequences and physico-chemical properties of purified preparations derived from different vertebrate sources [8].

These differences may be the basis of the phenomenon of 'species specificity' which expresses itself as the tendency of one species to respond poorly, or not at all, to pituitary hormones from another. Nevertheless, the mammalian pituitary is still capable, in some instances, of stimulating the piscine gonad; the converse is also true [9–11, 27].

This situation is of fundamental importance to the fish culturist. A few species of fish will yield ripe eggs or sperm when treated with mammalian pituitary extracts, but most will not. The gonadotropic hormones extracted from pregnant mare serum or human pregnancy urine rarely work any better. The fish culturist is therefore seldom able to use commercially available extracts. Instead, he must employ preparations of fish pituitaries that he has to make himself.

Numerous endocrinological experiments on mammals and birds are most easily explained by postulating that the pituitary produces two gonadotropins. Chemical separation of the follicle-stimulating hormone (FSH) and luteinizing hormone (LH) has been reported in numerous investigations. Nevertheless, the possibility that the naturally occurring gonadotropin is a single, multipurpose hormone which is broken down by chemical fractionation cannot be excluded, and the duality of the gonadotropins has been repeatedly questioned [12].

The problem is equally complex in fishes. There is no evidence that fish respond to mammalian FSH [13], whereas the piscine gonad is readily stimulated by LH. Yet, by mammalian assays, both FSH and LH activities appear to be present in the fish pituitary [10, 14]. Moreover, studies of the maturation of fish gonads and their regulation by environmental conditions suggest that different processes may be concerned in the earlier and later stages, and that ovulation is an independent event. In some species [15] only the second process (yolk production) is light-dependent, and in most species the third (ovulation) does not occur unless suitable environmental conditions prevail [16]. Different processes suggest the release of different pituitary hormones. Moreover, the synergic action of growth hormone, thyrotropic hormone, and sex steroids is strongly indicated and may account for the better results obtained with crude than with purified gonadotropic preparations.

The regulation of the release of pituitary gonadotropins, initiated by environmental stimuli, is mediated through hypothalamic centres at the base of the brain. In warm-blooded vertebrates there is a hypothalamo-hypophysial portal system, a local vascular connection, that is believed to carry neurosecretory products from the hypothalamus to the hypophysis and thus to participate in the production and release of pituitary hormones. A similar arrangement exists in sharks and rays, but the bony fishes lack this vascular connection [17], and neurosecretory products are apparently

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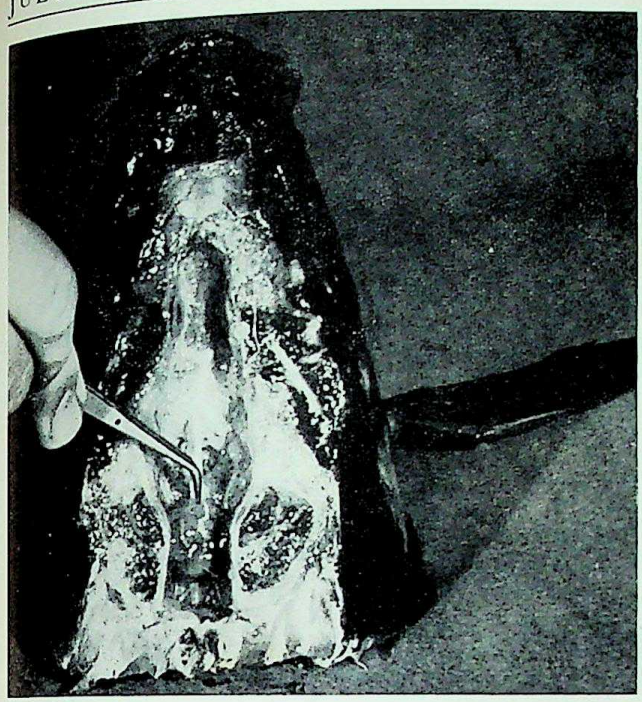

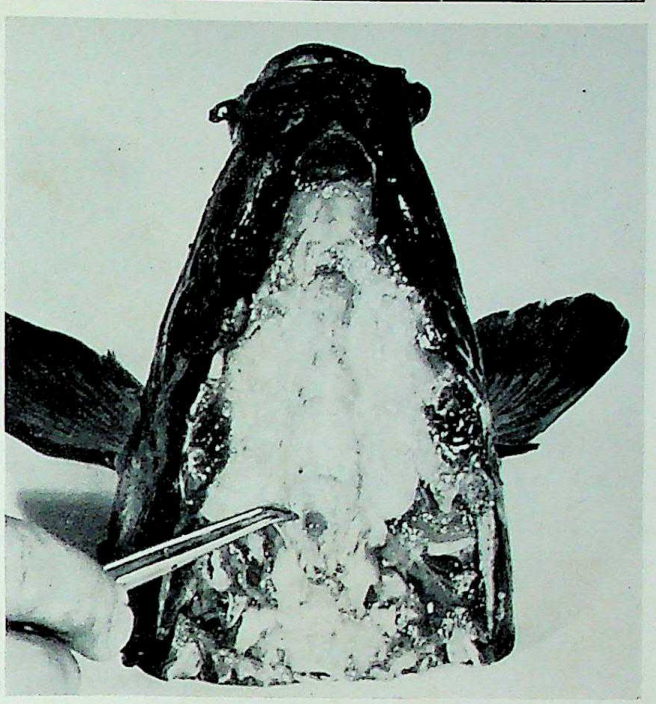

FIGURE 1 – *Dissection of fish to obtain pituitary gland. (Left) First stage: head of carp with brain case removed to expose brain. (Right) Second stage: brain removed to expose pituitary. (By courtesy of Robert C. Ball.)*

transmitted from the hypothalamus by way of nerve fibres which, in this group, ramify throughout the hypophysis [18]. Numerous studies have shown that specific hypothalamic centres in the teleostean brain undergo seasonal changes in secretory activity correlated with the reproductive cycle [19, 20].

The theoretical considerations outlined above have had an important bearing on the practical procedures that we are about to discuss. Brazilian fish culturists soon improved their simple yet successful technique. They learned that donor fish must be in the right stage of the reproductive cycle, because, if they are immature or have recently spawned, their pituitaries are ineffective owing to the low concentration of gonadotropin. Glands from a variety of donor species could be preserved for future use by dehydrating them in acetone or absolute alcohol. Females generally required higher doses than males. Small multiple injections gave better results than did single large ones. In practice, from four to eight intramuscular injections are given, usually at six-hour intervals, until the fish show by their behaviour that they are ready to spawn. A partition separating males from females in the aquarium is then removed and spawning is allowed to take place. The total amount of pituitary extract administered may be equivalent to as little as one-half or to as much as five glands, depending on the responsiveness of the recipient.

By far the most extensive use of pituitary treatment in pisciculture has been made in the Soviet Union. The Russians first attempted to induce captive sturgeons to ripen or spawn in 1932 by means of mammalian hormones, but it was not until 1937 that N. L. Gerbil'skii was able to obtain ripe eggs and sperm from a significant number of sturgeon (*Acipenser stellatus*) that had been intracranially injected with one or two fresh pituitaries of the same species. Since then pituitary treatment has played an ever-increasing role in the conservation of sturgeons in Russia. More and more dams, locks and hydro-electric plants are being built along the Russian rivers, and these present insurmountable barriers to sturgeon, which must travel upstream to spawn. Stations for sturgeon culture at one time had to be located near the spawning grounds; with the advent of artificially induced ripening these could be moved near the mouths of the rivers, since the final stages of maturation could now be hormonally effected. In 1950, the latest year for which figures are available, nearly nine hundred females belonging to the two most commercially important Russian species of sturgeon were treated. Today the Russians obtain all sturgeon eggs for culturing from pituitary-treated fish [21].

For this purpose, sturgeon pituitary glands are collected on a large scale, utilizing fish taken in the extensive commercial fisheries. A team of four men can remove and preserve about five hundred

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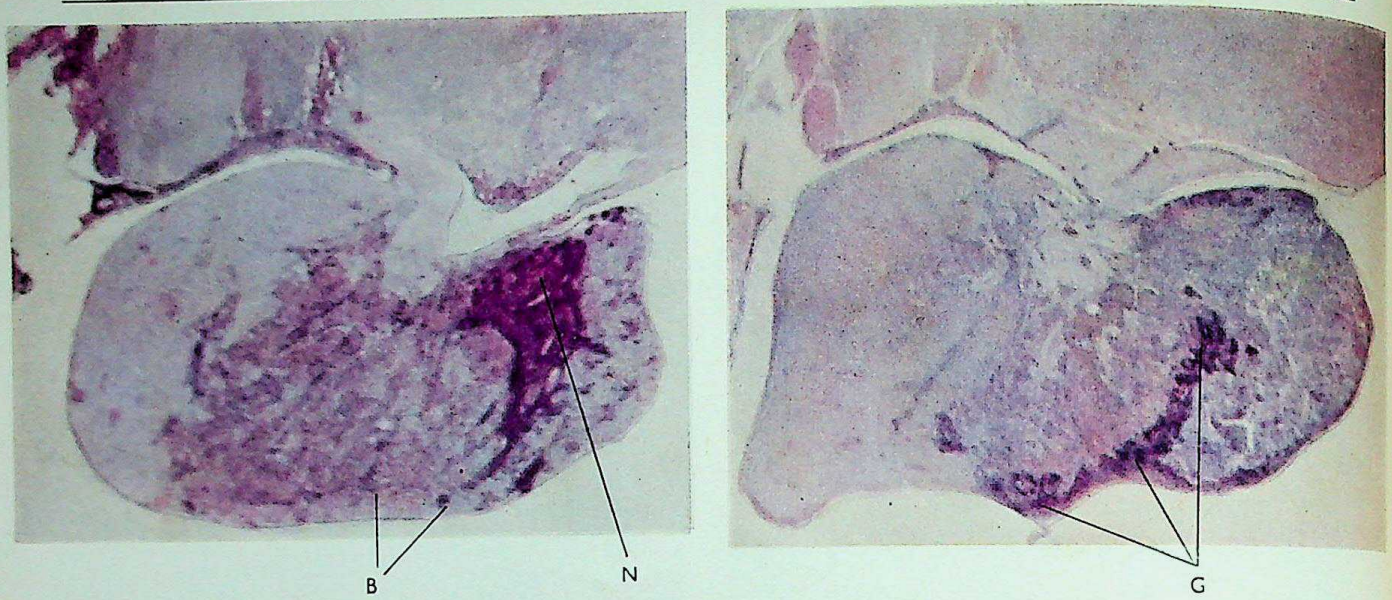

FIGURE 2 – *Seasonal changes in the hypophysis of the killifish,* Fundulus heteroclitus, *correlated with sexual maturation and regression. Sagittal sections of the pituitary gland of male fish, fixed in Bouin's fluid, sectioned at* 4 μ, *and stained by the aldehyde fuchsin (AF) method. (Left) In December (winter regression). The basophils (B) of the meso-adenohypophysis* (Übergangsteil) *are small and show comparatively few AF-positive granules in the cytoplasm. The neurohypophysis contains abundant accumulations of neurosecretory material (N).* (*Magnification* × 380.) (*Right*) *In May (early in breeding season). About half of the basophils of the meso-adenohypophysis are large and filled with deep purple AF-positive granules (G). The most peripheral basophils of this zone, which are sparsely granulated at this time, would be densely packed with AF-positive material in June. Neurosecretory material is sparse in the neurohypophysis.* (*Magnification* × 220.) (*By courtesy of Hilda Weyl Sokol.*)

glands a day.[1] After dehydration in acetone, the glands are stored dry in tightly sealed bottles. A single intramuscular injection of aqueous extracts from two to four glands is given to each fish, which is maintained along with others like it in a pond furnished with running water. In order to make certain that the gonads of females are sufficiently mature before injection, they may be inspected through an incision in the body wall. Injected males and females are kept together and examined periodically for the correct stage of ripeness, at which time the females are opened and their eggs artificially fertilized with milt taken from males. Gerbil'skii's method of injecting the pituitary material inside the skull is no longer employed, probably because of the high degree of skill required to avoid serious injury to the fish.

Not all the sturgeon that enter a river are mature enough to be able to respond to pituitary treatment; in fact, a species may be divided into as many as four different seasonal 'races', each race being characterized by a different time of entry into the particular river in question. Some races proceed immediately to the spawning grounds; others require several weeks before they ripen; still others remain more than six months in fresh water, hibernating over winter, before they spawn. The necessity of adapting pituitary treatment to this situation has stimulated the Russians to study the phenomenon of biological races among fish that migrate into fresh water to breed, and to attempt to correlate their existence with the different ecological conditions found in various rivers [22].

Experiments on the pituitary treatment of fishes have also been performed in at least eight European countries and in Japan and in Argentina, apparently without practical application to pisciculture. The reasons for this are not far to seek. Fish culture is relatively unimportant in most temperate countries, and those species that are raised in quantity, such as carp and rainbow trout, respond well to techniques that were perfected long before the functions of the pituitary were understood. In the United States, however, the injection of fishes with pituitary hormones is now regularly employed to produce goldfish for the pet trade, and also to obtain goldfish-carp hybrids. These latter are useful as bait, since they

[1] Much faster work can undoubtedly be done with the use of a meat-cutter's band-saw, at least in the case of such species as carp, cod, pollack, and hake. We have found that a team of two workers, a head-cutter and a gland-picker, can process as many as 500 fish heads in an hour by this means.

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are sterile and cannot overrun streams or lakes and spoil them for native food- and game-fish, as the parent species have done in the past. The method is now being adapted for the mass production of native minnows for bait, the culture of channel catfish (*Ictalurus punctatus*), and the conservation of Pacific salmon (*Oncorhynchus* spp) that have been prevented from reaching their upstream spawning areas by man-made obstacles. Unfortunately, methods that were successful with trout (*Salmo* spp) have so far proved almost total failures with salmon (*Oncorhynchus* spp) [23].

Promising developments have recently occurred in India. The principal problem in Indian fish culture has been obtaining seed fish regularly. When the monsoons failed or other unfavourable conditions prevailed during the spawning season, serious shortages of food-fish resulted. H. Chaudhuri of the Central Fisheries station at Cuttack, Orissa, has now been able to induce spawning in six species of carps with as little as a single intramuscular injection derived from one twenty-fifth of an alcohol-preserved gland taken from one of a number of species of donor carp [24]. The practicability of the pituitary method for Indian pisciculture was established beyond doubt in 1958, when fishery officers were successful with it in five other states [25]. In addition, three species of freshwater catfish from India have been treated successfully, two of them with mammalian hormones [26].

In most of the investigations cited in preceding paragraphs the problem has been relatively simple, since hypophysis injections could be administered to fish already close to natural spawning. However, the Russians have found it necessary to keep sturgeon of certain biological races in ponds for weeks or months until they reached the right stage of maturation, after which a single hypophysis injection is effective. The induction of growth and maturation of the gonads in fish that fail to approach sexual maturity under conditions of pond culture presents an acute problem. Most of the species of carp employed, for example, in the Chinese method of mixed carp culture, rarely if ever mature. The same is true of the milkfish, the striped mullet, and the Siamese catfishes (*Pangasius* spp). Although complete maturation of the regressed testes of hypophysectomized fish has been achieved as a laboratory experiment, no similar results have been reported for the reproductive organs of the females. Even if such results could be produced by treatment with suitable mixtures of hormones over long periods of time, it is doubtful whether this problem could be solved on a practical basis by hormonal treatment alone. Attention must rather be given to the improvement of environmental conditions favouring natural maturation of the gonads in breeder fish.

It is hoped that the foregoing brief account may serve as a stimulus to pisciculture, especially in those areas of acute protein shortage in which difficulties of domestication have hampered pond culture.

REFERENCES

[1] RADCLIFFE, W. 'Fishing from the Earliest Times'. Dutton, New York. 1921.

[2] LIN, S. Y. *Proc. Indo-Pacific Fish. Council, 1st Meeting, March* 1949, 65, 1949.

[3] CHEN, S. C. *Scientia Sinica*, **5**, 287, 1956.

[4] SMITH, H. M. *Bull. U.S. nat. Mus.*, (188), 456, 1945.

[5] LIN, S. Y. *Proc. U.N. sci. Conf. Conserv. Utiliz. Resources*, 1949, **7**, 131, 1951.

[6] PICKFORD, G. E. and ATZ, J. W. 'The Physiology of the Pituitary Gland of Fishes'. New York Zoological Society, New York. 1957.

[7] ALLEN, E. (Editor). 'Sex and Internal Secretions' (second edition). Williams and Wilkins, Baltimore. 1939.

[8] GESCHWIND, I. I. 'Comparative Endocrinology'. Gorbman, A. (Editor). John Wiley & Sons, New York. (In the press.)

[9] LEBKOVA, N. P. Докл. Акад. Наук, СССР, **109**, 411, 1956.

[10] KIRSHENBLAT, Ia. D. *Ibid.*, **66**, 745, 1949.

[11] OTSUKA, S. *J. Sci. Suzugamine Coll.*, **3**, 129, 1956.

[12] DEMINALTI, M. and WEILL, J. D. *C.R. Soc. Biol., Paris*, **152**, 815, 1958.

[13] KIRSHENBLAT, Ia. D. Докл. Акад. Наук, СССР, 111, 504, 1956.

[14] OTSUKA, S. *Endocrinol. Japon.* **3**, 272, 1956.

[15] HARRINGTON, R. W. *J. exp. Zool.*, **135**, 529, 1957.

[16] GERBIL'SKII, N. L. Труды Карельск. Фил. Акад. Наук, СССР, **5**, 6, 1956.

[17] LEGAIT, H. *C.R. Soc. Biol., Paris*, **151**, 1940, 1957.

[18] LEGAIT, H. and LEGAIT, E. *Ibid.*, **151**, 1943, 1957; *Ibid.*, **152**, 130, 1958.

[19] STAHL, A. *Acta Anat.*, Suppl., **28**, 1, 1957.

[20] POLENOV, A. L. Докл. Акад. Наук, СССР, **112**, 1122, 1956.

[21] GERBIL'SKII, N. L. Уч. Зап. Ленинград. Гос. Унив. Биол. Наук, (228), 2, 1957.

[22] *Idem. Ibid.*, (228), 11, 1957.

[23] ROBERTSON, O. H. and RINFRET, A. P. *Endocrinology*, **60**, 559, 1957. Anon. *Progr. Fish-Culturist*, **21**, 44, 1959.

[24] CHAUDHURI, H. and ALIKUNHI, K. H. *Current Sci.*, **26**, 381, 1957.

[25] CHAUDHURI, H. *In litt.* 1958.

[26] RAMASWAMI, L. S. and SUNDARARAJ, B. I. *Acta Anat.*, **32**, 230, 1957.

[27] YOUNG, J. Z. and BELLERBY, C. W. *J. exp. Biol.*, **12**, 246, 1935.

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The mammalian egg

C. R. AUSTIN and E. C. AMOROSO

The egg is a most unusual cell, not only on account of its great size but also because it passes through a series of changes, here described, of so radical a nature that it is commonly referred to as though it were a succession of separate cells. The illustrations to this article have been obtained by a combination of classical and newly devised histological techniques that have all played a part in advancing our knowledge of the beginnings of embryonic development.

'Led by curiosity . . . I opened one of the follicles and took up the minute object on the point of my knife, finding that I could see it very distinctly and that it was surrounded by mucus. When I placed it under the microscope I was utterly astonished, for I saw an ovule just as I had already seen them in the tubes, and so clearly that a blind man could hardly deny it.' In these words von Baer announced his discovery to the world of 1827 and brought to an end a search that had gone on for over 2000 years [14].

In the fourth century B.C. Aristotle concluded from his patient and thoughtful investigations that many animals, including mammals, originated in the admixture within the uterus of menstrual blood and the male semen. From these materials, he maintained, a coagulum was produced that gradually became organized into the tissues and organs of the foetus. He did not associate the ovaries with the reproductive process and believed the semen was produced, not in the testes, but in the seminal ducts. The ovaries were first identified as being implicated in reproduction about 500 years later, when Galen taught that the female equivalent to the male semen was a substance of similar nature that was separated by the ovaries from the blood stream and passed down the Fallopian tubes to the uterus.

These beliefs were held for over fourteen hundred years. Then, in 1672, de Graaf published a book in which the mammalian ovary was clearly and accurately described, and evidence was brought forward showing its function to be analogous to that of the hen's ovary. De Graaf had found small round objects in the uterus of the rabbit that he termed 'eggs' (they were in fact blastocysts, like those shown in figure 18) and similar though smaller ones in the Fallopian tubes. He was unable to find anything but fluid within the follicles, but maintained that the contents of the follicle were released and, passing through the Fallopian tube, became constituted into the 'eggs' from which the embryo would eventually hatch within the uterus.

Despite the attempts of numerous investigators, de Graaf's observations on tubal embryos were not confirmed for many years and, as no one could find recognizable structures in the follicle either, much of his theory fell into disrepute. Just over a century later, in 1797, Cruickshank reported that he too had observed tubal eggs in the rabbit on the third day after coitus, and uterine embryos at later stages (figure 19). But, like de Graaf, Cruickshank was quite unable to trace the history of these objects back through the first few days. A further careful investigation, by Prévost and Dumas in 1824, was equally fruitless, though these authors must have come very close to success, for they mentioned finding small bodies about 1 mm in diameter in some follicles, and these could well have been eggs with their investments of cumulus cells. It was thus left to von Baer to recognize the egg in the ovary (figure 20) and finally to identify the source and form of the female gamete.

Subsequent developments came comparatively quickly, and the modern concept of the nature and function of the mammalian egg was fully established within the next fifty years. The nucleus of the ovarian egg, the germinal vesicle, was described by Coste in 1834. Schwann suggested that the egg is a true cell, and Gegenbauer showed this to be so. Many detailed observations were published by Barry (figure 21), and especially by Bischoff (figure 22), on the eggs of rabbits, guinea-pigs, dogs, and deer. By the middle of the century it was known that the egg of the placental mammal consists of a cytoplasmic mass or vitellus surrounded at a short distance by a thick transparent membrane, the zona pellucida. The first real clues to the cytological changes at fertilization were provided through the perspicacity of Van

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Beneden and Hertwig, who showed, in 1875 and 1876 respectively, that a nucleus of new formation arose from the penetrating spermatozoon; they maintained that it was the union of this nucleus and the egg nucleus that constituted the essential act of fertilization. Notable studies on living rat eggs were made by Tafani, but it was the extensive and painstaking histological researches of Sobotta, towards the end of the nineteenth century, that were chiefly responsible for the rapid advances in detailed knowledge of maturation, fertilization, and early cleavage (figure 23).

The egg originates in the genital ridges of the embryo, where early germ-cells undergo several mitotic divisions and give rise to primary oocytes. These oocytes do not divide, but grow enormously in size and accumulate yolk material in their cytoplasm; they become surrounded first by a single layer of follicle cells and later by several layers. This system is the ovarian follicle. Progressive enlargement continues and the layers of enveloping follicle cells increase in number. Within the follicle there forms a space, the antrum, containing follicular fluid. A few hours before ovulation, the oocyte (figure 1) enters upon a process of maturation by extruding the first polar body, becoming thus a secondary oocyte (figures 2, 7, and 28). Separation of the second polar body (figures 3, 27, and 36), which marks the fulfilment of maturation, occurs in most mammals only after ovulation and entry of the spermatozoon.

After ovulation, the secondary oocyte passes to the Fallopian tube, where penetration by the spermatozoon initiates fertilization. Fertilization ends with the union of male and female chromosome complements (figure 8), and the egg divides into a 2-cell embryo (figures 5 and 9). Cleavage proceeds with a succession of mitotic divisions whereby the embryo comes to be composed of a large number of small cells (figures 10–14 and 39). At first these cells gather together as a solid structure known as a morula, but later a fluid-filled cavity develops, and this characterizes the blastocyst (figures 15–17 and 42). At one point on its inner surface the blastocyst bears a group of cells, the 'inner cell mass', from which the foetus itself will develop, while the wall of the blastocyst, the trophoblast, is destined to form the foetal membranes.

The sizes of mammalian eggs, which are not proportional to the sizes of the adult mammals, differ so very much that they cannot all be conveniently measured in the same units. The early germ cells and the newly formed primary oocytes are a little bigger than the other cells of the genital ridge, but, at various times after the birth of the animal, primary oocytes undergo their immense enlargement, in which the volume increases 80- to 90-fold. To varying degrees this is attributable to accumulation of non-living yolk materials. When they have reached their full size, the eggs of placental mammals measure 60–180 μ in diameter (vitellus alone); the eggs of rodents occupy the lower part of the range (figure 24). Very occasionally 'giant' eggs are found, which are 30–40 per cent larger in diameter than normal; these are known in the rabbit, rat, and mouse [5] and the cotton-rat (figure 38). The egg of the Australian native cat *Dasyurus*, is of notably larger dimensions, namely 240 μ in diameter, but much the largest mammalian eggs are those of the oviparous monotremes, the spiny anteater *Tachyglossus*, and the duck-billed platypus *Ornithorhynchus*, in which the vitellus at ovulation measures 3·5–4 mm in diameter. Sea-urchin (*Arbacia*) eggs are much the same size as rodent eggs, the vitellus having a mean diameter of 74 μ. By comparison, fish eggs vary between 400 μ and 150 mm, and frog eggs between 700 μ and 10 mm [8]. On the other hand, the oval egg of the parasitic nematode *Ascaris* has diameters of about 60 and 45 μ, and that of the trematode *Clonorchis* only 28 and 14 μ.

The eggs of placental mammals, with volumes between 100 000 and 3 000 000 μ^3, and that of *Dasyurus* with a volume of about 7 000 000 μ^3, are very big compared with most tissue cells, of which the volumes lie between 200 and 15 000 μ^3. A motor neurone in a large mammal, however, would have a volume of the order of 10 000 000 μ^3, mainly on account of its remarkably long axon. The smallest mammalian cells are probably the red blood cells and spermatozoa, of which the volumes are about 100 μ^3 and 30 μ^3 respectively.

THE NUCLEAR STRUCTURE OF THE MAMMALIAN EGG

The nucleus of the early germ-cell as seen in histological preparations contains a fine reticulum with scattered chromatin granules and one or two nucleoli. The oocyte nucleus is similar when first formed, but soon undergoes a series of changes that are part of the prophase of the first meiotic division. Meiosis does not occur, however; instead, the nucleus passes into a prolonged resting state, which persists until maturation begins at puberty or later. When the great enlargement of the oocyte occurs the nucleus grows also, to reach

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a relatively enormous size (figures 1 and 43)—about 18 000 μ^3 in the rat egg—which is larger than the whole volume of most tissue cells. A distinctive feature of the oocyte nucleus at this stage is the large nucleolus, about which exist high concentrations of deoxyribonucleic acid (DNA) (figure 1). Presumably this can be ascribed to aggregation of the partially condensed heterochromatic regions of chromosomes. The oocyte nucleolus contains little or no ribonucleic acid (RNA), which is a component of most tissue-cell nucleoli.

Maturation involves the reduction of the chromosome number to half, which is brought about in the course of two meiotic divisions. In the later stage of prophase, the chromosomes, already arranged as homologous pairs, can each be seen to have split into two units (chromatids), but each chromosome still has only one centromere. Crossing over of parts of homologous chromosomes now occurs, permitting rearrangement of genetic material. The modified members of the chromosome pairs are parted and move to opposite poles of the spindle, one group passing into the first polar body. The chromosomes then at once regroup on the second meiotic spindle. As a general rule, the second meiotic division is arrested at metaphase and proceeds only after ovulation and penetration by the spermatozoon. When it continues, the centromeres divide and the constituent chromatids of each chromosome separate, half of them passing into the second polar body. The chromatids thus become the chromosomes of the next generation.

Following the entry of the spermatozoon, both spermatozoon head and the group of egg chromosomes are transformed into nuclei, known as the male and female pronuclei respectively. There is an apparent hydration of the head and a clumping of the egg chromosomes (figure 3; the polar-body chromosomes lying at a lower focal plane are also visible). Within each mass, nucleoli make their appearance, and soon an encircling nuclear membrane becomes evident. A detailed account of fertilization appears in a recent review [7].

Pronuclei contain one or often more nucleoli suspended in a fluid medium, the nucleoplasm (figures 4, 23, 31, 32, and 33). The number may often be greater than the haploid chromosome number of the animal: in male pronuclei in rat eggs, for example, as many as 35 nucleoli have been recorded, although the haploid number in the rat is only 21. This may mean that nucleolar materials can accumulate to visible proportions in sites other than the nucleolus organizer present on certain chromosomes, or that there is more than one nucleolus organizer on any one chromosome, or that nucleoli can be detached from their sites of formation, leaving the positions free for the development of further nucleoli.

Larger eggs tend to have relatively smaller pronuclei, probably because they carry more yolk. Thus the ratio of pronuclear volume to vitelline volume at the peak of pronuclear growth is 1 : 25 in the rat egg and 1 : 88 in the rabbit egg. As in other cells, there may be a direct relationship between the nuclear size and the mass of active protoplasm. The size of nucleoli relative to that of the pronuclei also differs in different eggs. In the living rat egg the total volume of nucleoli is approximately one-tenth that of the pronuclei; in the rabbit egg, on the other hand, it is only one-hundredth. Observations on the living eggs of other rodents and on the fixed eggs of various mammals show that small eggs have relatively large nucleoli and large eggs often have small nucleoli (compare figures 31, 32, and 33). Large nucleolar size is generally held to be associated with a high rate of protein synthesis. Perhaps this means that small eggs, with their more limited stores of nutrient materials, must undertake more intense synthetic activity.

Studies on centrifuged eggs show that the nucleoli are of higher specific gravity than the other components of the pronucleus. Pronuclear nucleoli consist chiefly of basic protein and phospholipid and possess little or no nucleic acid. They contain acid phosphatase, and also inclusions of mucopolysaccharide which some authorities believe are passed into the cytoplasm as specific products of nuclear synthesis [15].

The nucleoplasm in the pronuclei of living eggs is structureless when viewed with the phase-contrast microscope, though it is presumably occupied by the chromosomes in an extended form. Moderate concentrations of DNA are readily demonstrable in early pronuclei, uniformly distributed through the nucleoplasm (figure 4). The amount of DNA in each pronucleus is half that present in tissue-cell nuclei, for DNA is the characteristic component of chromosomes and the pronuclei contain half the somatic number of chromosomes (like the egg, the spermatozoon loses half its chromosome complement during maturation). As the pronuclei grow, the concentration of DNA falls, for the total amount remains constant. Later in pronuclear life, however, an extra complement of DNA accumulates

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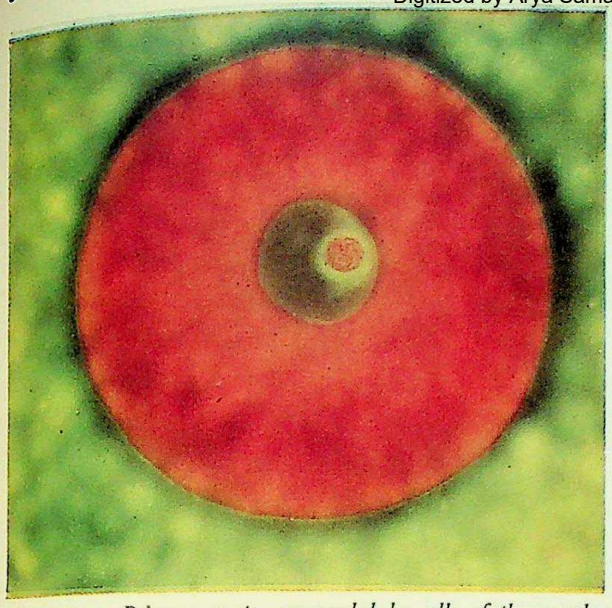

FIGURE 1 – *Primary oocyte, surrounded by cells of the cumulus oophorus.*

FIGURE 2 – *Secondary oocyte (unfertilized tubal egg) with the green fluorescent chromosomes on the second meiotic spindle.*

FIGURE 3 – *Early fertilization; the spermatozoon head and the telophase chromosome groups fluoresce green.*

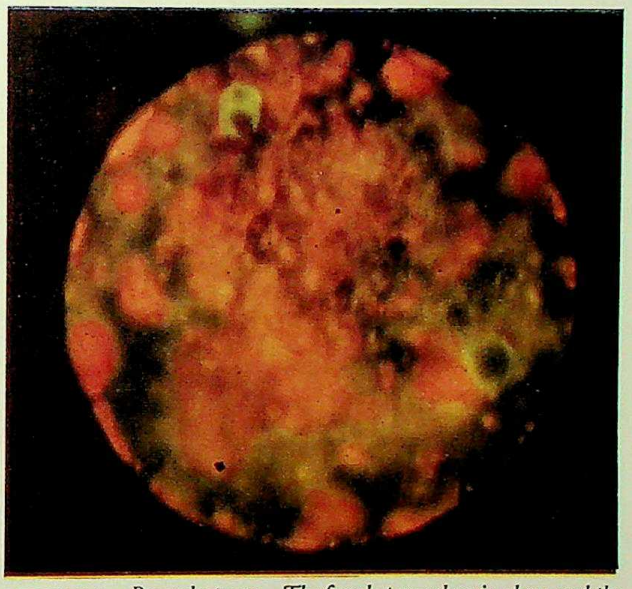

FIGURE 4 – *Pronucleate egg. The female pronucleus is above and the male below and to the right.*

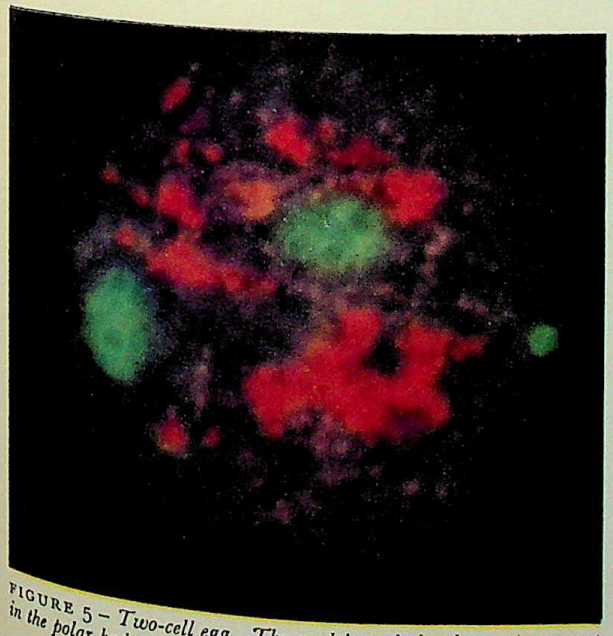

FIGURE 5 – *Two-cell egg. The nuclei, and the chromosome group in the polar body, fluoresce green.*

FIGURE 6 – *Eight-cell egg. The aggregated cytoplasmic granules fluoresce red.*

FIGURES 1–6 – *Stages in the development of rabbit eggs, showing fluorescence induced by treatment with acridine orange (ca. × 500; eggs somewhat flattened by coverslip).*

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FIGURE 7 – *Secondary oocyte with second meiotic chromosomes.*

FIGURE 8 – *Syngamy. Fat droplets stained.*

FIGURE 9 – *Two-cell egg with a second-cleavage spindle.*

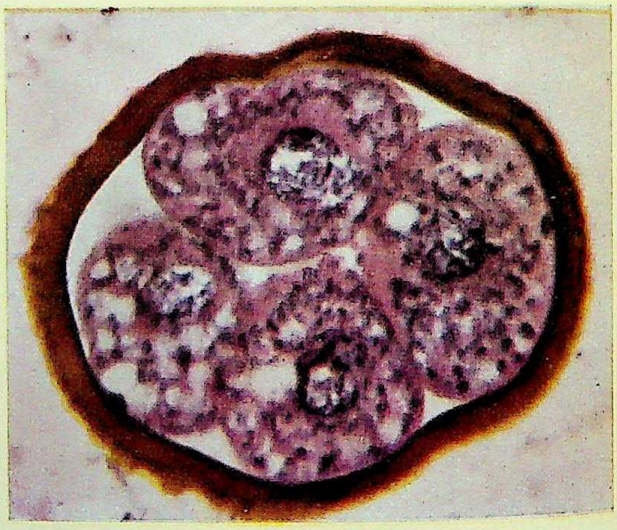

FIGURE 10 – *Four-cell egg.*

FIGURE 11 – *Eight-cell egg; only six of the blastomeres are visible in this section.*

FIGURE 12 – *Morula. Fat droplets stained.*

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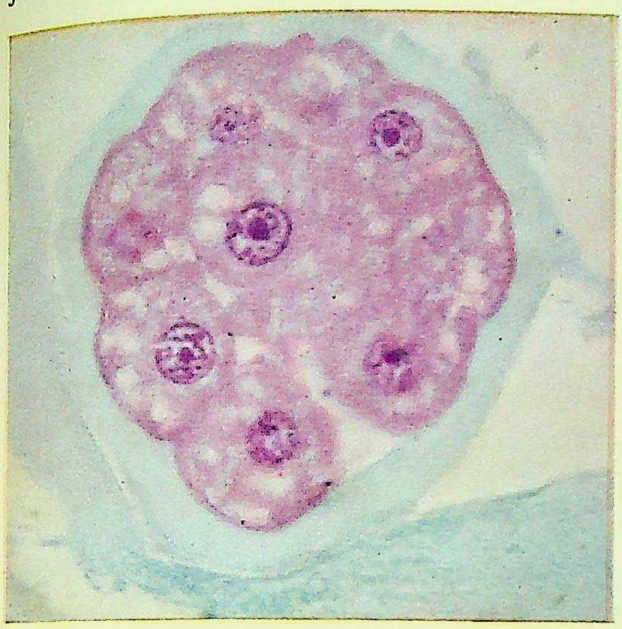

FIGURE 13 – *Morula.*

FIGURE 16 – *Blastocyst.*

FIGURE 14 – *Morula.*

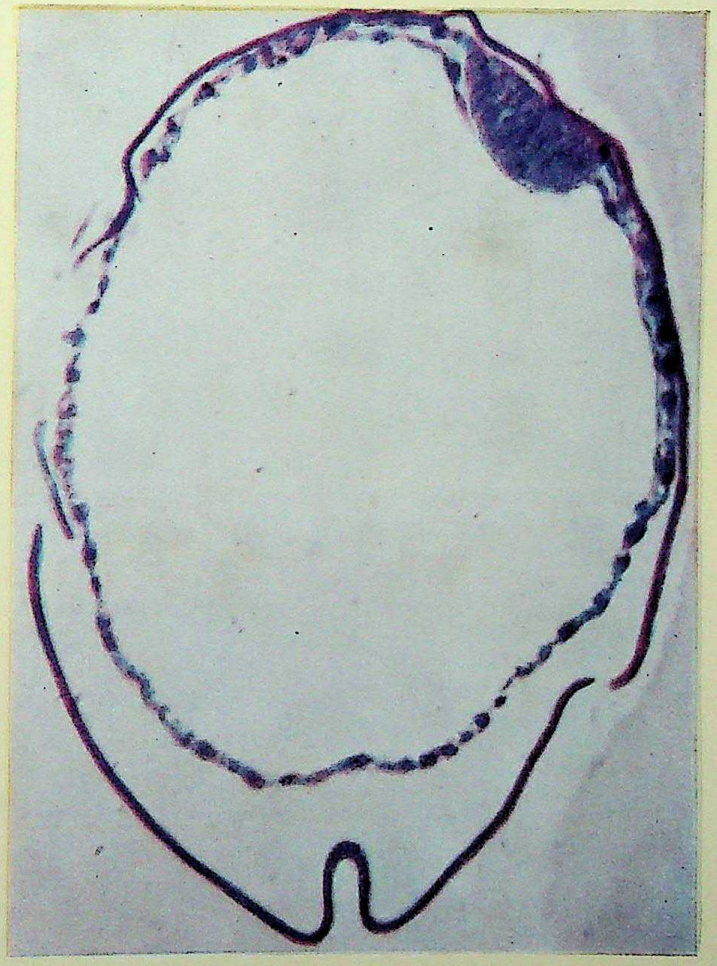

FIGURE 17 – *Blastocyst.*

FIGURE 15 – *Blastocyst.*

FIGURES 7–17 – *Stained sections of cat eggs.* (*Figures* 7–14 × 700, *figure* 15 × 550, *figure* 16 × 450, *and figure* 17 × 270.)

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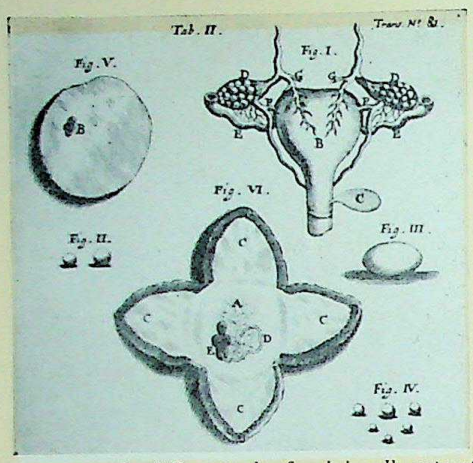

FIGURE 18 – "*Eggs to be found in all sorts of Females*" (*Kerckring*, 1672).

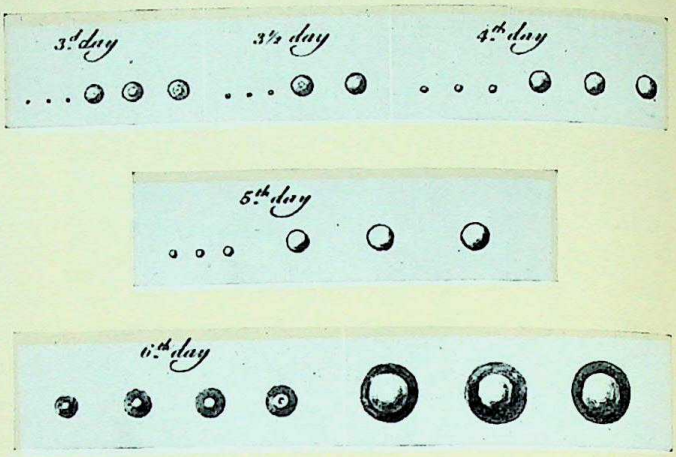

FIGURE 19 – *Rabbit eggs, natural size and enlarged* (*Cruickshank*, 1797).

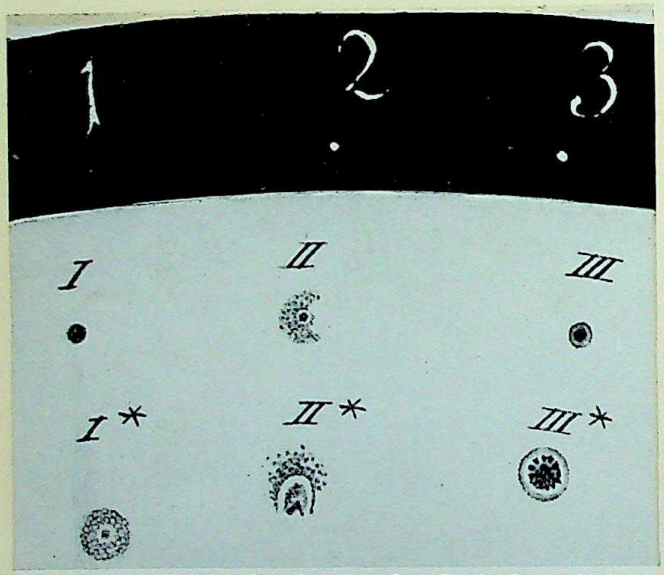

FIGURE 20 – *Slightly enlarged portion of von Baer's plate, published in* 1827. *Magnification on original plate: top row, natural size; middle row* × 10; *bottom row,* × 30.

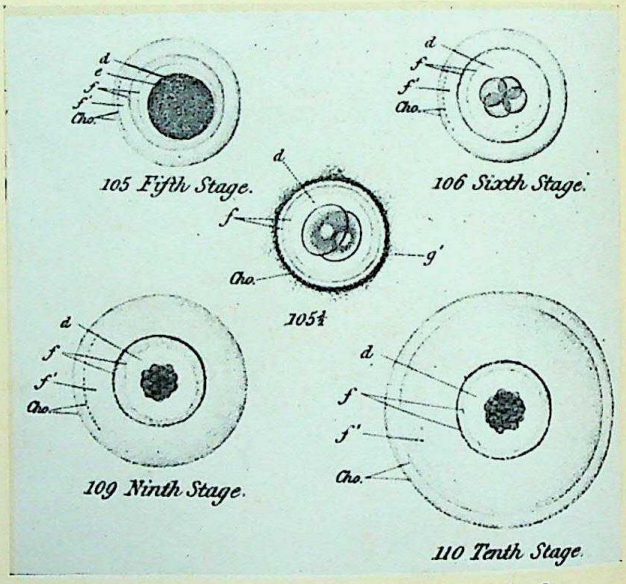

FIGURE 21 – *Rabbit eggs as depicted by Barry in* 1839.

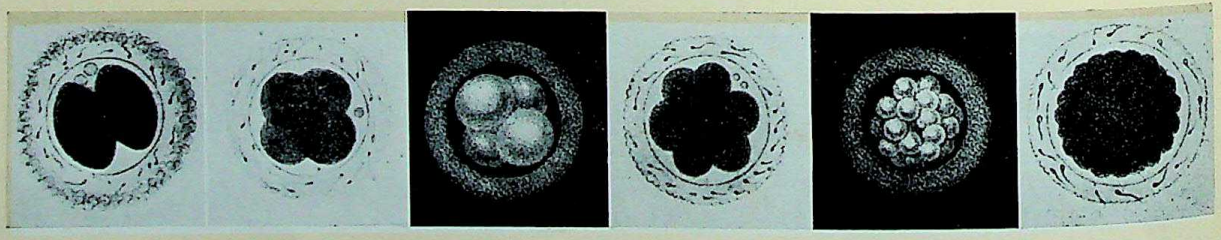

FIGURE 22 – *Dog eggs described by Bischoff in* 1845.

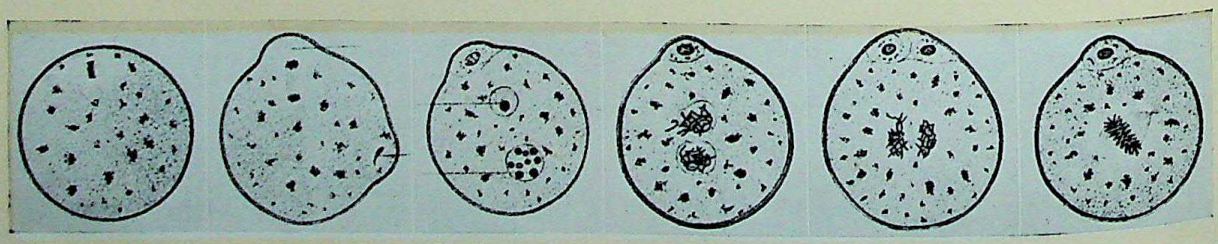

FIGURE 23 – *Fertilization in the mouse egg according to Sobotta*, 1895.

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in each pronucleus; the new material is synthesized from cytoplasmic substrate, which is said to include mucopolysaccharide and acetalphosphatide [15]. Thus the pronuclei come to contain between them twice as much DNA as there is in a tissue-cell nucleus. The increase in DNA is attributable to the doubling of the chromosome number which occurs at this time. When the fertilized egg divides into a 2-cell embryo, each of the new nuclei will contain as much DNA and as many chromosomes as a tissue-cell nucleus.

One pronucleus may be noticeably larger than the other. In the rat and mouse, the volume of the male pronucleus is about two and a half times that of the female (figure 43). An adequate explanation for this rather curious feature is still lacking. In certain other animals, such as the rabbit and Libyan jird *Meriones libycus* (figures 32 and 31), a distinct disparity in size also exists, but for these animals it is not yet established whether it is the male pronucleus or the female pronucleus that is the larger. Sometimes the pronuclei are very nearly equal in size, as in the golden hamster *Mesocricetus auratus* (figure 33).

The nuclear membrane of tissue cells appears to be double except at the 'pores', where a single membrane exists. The double structure and the pores have been interpreted also in electron-micrographs of sea-urchin oocytes [1]. There is evidence that products of nuclear synthesis may reach the cytoplasm through the pores [2]. It has also been reported that nucleoli may be extruded into the cytoplasm in amphibian and mammalian oocytes, which is probably the same phenomenon in a different guise. The apparent development of vesicles in the membrane of the isolated 2-cell nucleus shown in figure 34 is consistent with the idea that the membrane is composed of two layers.

Cytoplasmic cleavage of the fertilized egg begins as the mitosis reaches telophase, and shortly after its completion nuclei reform from the chromosome groups. As in the genesis of the female pronucleus, nucleoli develop within each chromosome group as it disappears and a nuclear membrane becomes evident.

The 2-cell nuclei resemble pronuclei in usually having several nucleoli. The distribution of DNA is also similar except that there is a slightly higher concentration immediately round each nucleolus (figure 5). As cleavage proceeds through the 4-, 8-, and 16-cell stages, the nuclei diminish progressively in size (the volumes are approximately halved at each stage) and the nucleoli become fewer (figure 43). Concurrently, the concentration of DNA around the nucleoli increases very strikingly (figure 6); indeed, the arrangement comes to resemble that of the nucleolus-associated chromatin that was identified by Caspersson as part of the protein-synthesizing system of actively growing or secreting tissue cells. But there are two important differences: 8-cell nucleoli appear to have little or no RNA and the cytoplasm lacks the characteristically high concentration of this nucleic acid. These conditions develop later, in the implanted embryo; until implantation, extensive protein synthesis is evidently not a function of embryos in cleavage stages. If synthesis is in fact proceeding in the nuclei it may well be concerned with the production of the extra DNA which is required to maintain the diploid equivalent at each stage of cleavage.

THE CYTOPLASM

The egg cytoplasm, like the cytoplasm of most other body cells, is made up of the living substance or protoplasm and non-living nutrient materials constituting the yolk. The protoplasm of the typical body cell appears to consist largely of the endoplasmic reticulum or ergastoplasm and numerous small bodies, including the mitochondria (which contain most of the enzyme systems), the Golgi components, and the centrosome. Minute particles, the microsomes and related structures, with which cytoplasmic RNA appears to be almost exclusively associated, generally form integral parts of the ergastoplasm. Electron-micrographs of sea-urchin eggs show a similar pattern of organization [1], and it can reasonably be inferred for mammalian eggs.

Yolk takes different forms in different mammals. The yolk mass in the monotreme egg is very large and resembles that of the hen egg. The future embryo is represented by a small germinal disk on the surface of the yolk (figure 24). In the Australian native cat *Dasyurus* [17] and the armadillo *Dasypus* [19], the greater part of the yolk material is gathered in a distinctly bounded region at one pole of the vitellus; in *Dasyurus* the yolk composes a third body in the 2-cell egg and retains this form during early cleavage (figure 24). The yolk in placental eggs is scattered throughout the vitellus, either as numerous large droplets of fatty material, as seen in the cat egg (figures 8 and 12), and to a less extent in the eggs of the güinea-pig (figure 36), bat (figure 27), and several other animals, or as various forms of granules, particles, or minute aggregates. Sometimes the distribution is uneven

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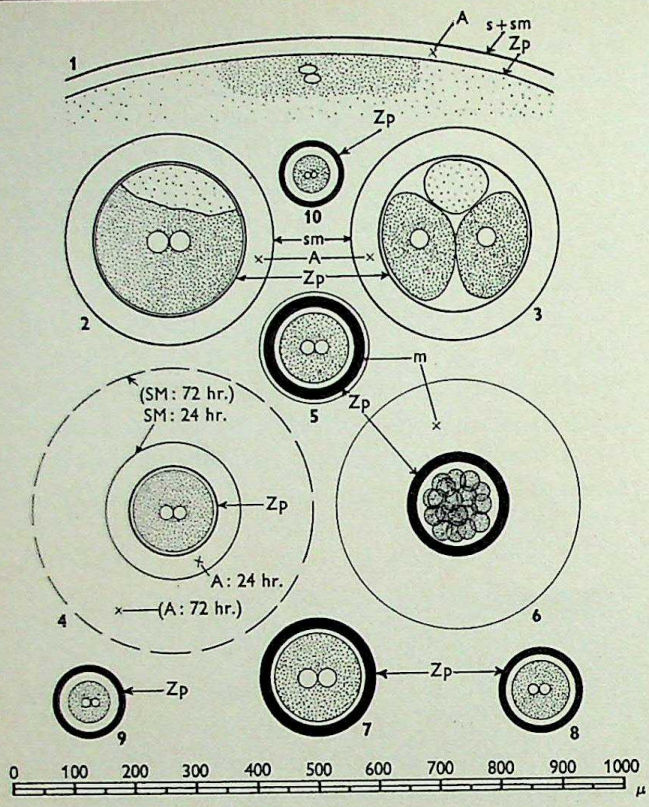

FIGURE 24 – *Sizes of mammalian eggs. Pronucleate eggs except Nos.* 3 *and* 6. (1) *The spiny anteater* Tachyglossus. (2) *and* (3) *The Australian native cat* Dasyurus. (4) *The American opossum* Didelphis, *at* 24 *hr after coitus; disposition of shell membrane and albumen layer at* 72 *hr also indicated.* (5) *and* (6) *Rabbit,* 10 *hr and* 72 *hr after ovulation respectively.* (7) *Sheep.* (8) *Man.* (9) *Golden hamster* Mesocricetus auratus. (10) *Field vole* Microtus agrestis. *A = albumen layer. M = mucoprotein layer. S = shell. SM = shell membrane. Zp = zona pellucida.*

and the egg has a distinct polarity. In general, the smaller the egg the less yolk it contains. Many eggs shed granular masses of yolk material from the vitellus into the perivitelline space, particularly during cleavage; this is especially well seen in the opossum *Didelphis* [16].

In frog and sea-urchin eggs there are quite large cytoplasmic stores of DNA, which are presumed to supplement the nuclear DNA as required at successive stages of cleavage. As yet, DNA has not been detected in the cytoplasm of mammalian eggs, and so the nucleic acid present must be considered as RNA only. The distribution in the rat has been found to be more or less uniform in the primary oocyte, in the egg during fertilization, and in the 2-cell embryo, but the RNA tends to gather about the nuclei in the later stages of cleavage. The total amount present is quite low until implantation of the embryo. Denser accumulations are said to characterize those blastomeres that will eventually form the inner cell mass of the blastocyst [15]. The ultra-violet absorption of living eggs suggests that higher concentrations of RNA occur in association with granular elements of the cytoplasm (figures 40 and 41); it is possible, however, that absorption is due, in part at least, to the presence of mononucleotides, which are contained very largely in the mitochondria. The similarity between the distribution of mitochondria and the arrangement of the red-fluorescent granules in eggs treated with acridine orange (figures 1–6) provides support for the idea that, under conditions such as those existing in living rat eggs, red fluorescence is caused by mononucleotides [4].

In the eggs of many non-mammalian species the centrosomes and their associated spindles and asters play an important and readily demonstrable role. At the approach of maturation, centrosome and aster divide into two parts which move towards opposite sides of the nucleus, the achromatic spindle develops between them, and thus an amphiaster is formed. The chromosomes become arranged on the equator of the spindle at the start of the first meiotic division. After the expulsion of the first polar body, the centrosome and aster remaining within the vitellus divide again and give rise to the spindle for the second meiotic division. When the second polar body has been formed, the vitelline centrosome and aster normally regress. The centriole introduced by the fertilizing spermatozoon is held to be responsible for the development of the centrosome, aster, and spindle required for the first cleavage division of the egg. At each subsequent cleavage, mitosis is preceded by division of centrosomes that are the descendants of the one that arose from the spermatozoon centriole. If, however, spermatozoon penetration does not occur and the egg is artificially activated, a centrosome and aster may reappear in the cytoplasm and serve the same functions as those normally fulfilled by the spermatozoon products. This is the case in parthenogenetic development.

Centrosomes and asters are more difficult to demonstrate in mammalian eggs, but their presence has often been reported in histological preparations. Mammalian-egg asters never seem to be as large or well developed as those in non-mammalian eggs. Spindles, however, are clearly visible, even in living eggs, provided these are examined by phase-contrast microscopy, when it is sometimes possible to see a suggestion of their fibrillar structure. Metaphase sipndles, such as those of the first and second meiotic divisions

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(figures 26 and 28), and the telophase spindle before expulsion of the polar body (figure 25) are characteristically barrel-shaped or elliptical in form. By contrast, telophase cleavage spindles and meiotic spindles after polar-body emission are long and cylindrical (figures 9 and 27). Typically, a disk-shaped aggregation of granules (the 'central body') (figure 25) runs across the centre of telophase spindles—its significance is unknown. Meiotic chromosomes are relatively compact structures, lying mostly within the bounds of the spindle; cleavage chromosomes are more extended in form and project from the spindle, often to some distance (figure 29). The group shown in this figure is asymmetrical because of the very large sex chromosomes in the vole; in the polar view (figure 30) the remarkably large X-chromosome can be seen (the Y-chromosome in this preparation lay out of focus).

EGG MEMBRANES AND COVERINGS

As in tissue cells, the cytoplasm of the egg is bounded by a plasma membrane, which may reasonably be supposed to have the same general properties of permeability and active transport. In addition, the vitelline plasma membrane seems to display special features. When the fertilizing spermatozoon makes contact with the vitellus its head becomes firmly attached to the surface, and this is a prelude to its absorption into the vitellus; no attachment is made with subsequent spermatozoa, and their entry is thus precluded. The change in response to spermatozoon contact is the essential feature in the prevention of polyspermy. The precise role played by the plasma membrane in the process, however, is not known.

The vitellus is surrounded by a narrow fluid-filled perivitelline space, which is bounded externally by the transparent zona pellucida, a membrane that is most developed in the placental mammals (figure 24). It is composed of mucoprotein [12] and seems to lack distinctive structure, even when examined by electron-microscopy. The zona pellucida is laid down around the early oocyte, probably through the mediation of the surrounding follicle cells, from which fine processes retain connection with the vitelline surface until shortly before ovulation. After ovulation, the thickness of the zona pellucida in most animals does not alter noticeably unless and until blastocyst expansion occurs, when the membrane becomes extremely attenuated. In the cat, however, the appearance of eggs at successive stages shows that the thickness of the zona pellucida increases during cleavage, prior to expansion of the blastocyst (figures 7–14). In interpreting these figures it is necessary to take into account the effects of different fixatives upon the zona pellucida. Fixatives containing acetic acid tend to dissolve the membrane, and, depending upon the conditions of fixation, they cause rarefaction of its substance, as in figures 11 and 13, or diminution of its thickness, as in figure 12. The additional material is seemingly of the same composition and is presumably supplied through the secretory activity of the Fallopian tube. The process somewhat resembles the deposition of an albumen or mucin layer which, as will be noted later, characterizes the eggs of some mammals.

When a spermatozoon passes through the zona pellucida it leaves a narrow slit, which may be attributable to the action of a lytic agent carried by the perforatorium of the spermatozoon [3]. Permeation of the zona pellucida occurs again at a later stage—just before implantation, when long mobile cytoplasmic processes arise from the trophoblast cells at the pole of the blastocyst most distant from the embryo and grow out through the zona pellucida [10]. It is believed that these processes initiate implantation by establishing contact with the endometrium. For their passage through the zona pellucida they may well depend upon the action of a lytic agent similar to that carried by the spermatozoon.

In most of the mammals that have been investigated the zona pellucida becomes impenetrable to spermatozoa after the entry of the first. The change is known as the zona reaction; it is thought to be induced by some substance released from the vitelline cortex, as a result of spermatozoon contact, that alters the properties of the zona pellucida, rendering it resistant to the action of the hypothetical lytic agent. In the hamster egg the disappearance of distinctive cortical granules (marked by loss of surface light-refraction—figure 37) seems to be linked with the release of the zona-modifying substance. The zona reaction helps to protect the egg against polyspermy.

When the egg leaves the Graafian follicle at ovulation it is accompanied by many of the surrounding follicle cells embedded in a hyaluronic-acid matrix (figure 35). This investment, the cumulus oophorus, persists in the absence of coitus for about twelve hours in some animals (the rabbit and the rodents) but for perhaps only an hour or so in others (the ungulates). When the cumulus remains it represents a possible barrier

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to the entry of spermatozoa, and it is probable that the enzyme (hyaluronidase) that they carry enables the spermatozoa to make their way through the cumulus.

In some animals the eggs become coated with a thick albuminous or mucinous layer as they pass down the Fallopian tube (figure 24). In addition, monotreme eggs are covered by a tough shell membrane; in the uterus they receive more albumen and finally a hard shell. In the marsupials *Setonix* [22], *Dasyurus* [17], and *Didelphis* [16] some further increments of albuminous material are added in the uterus, and these eggs also have a shell membrane. Among the placental mammals only the rabbit has been reported to possess the tubal mechanism for depositing an albuminous or mucinous coat about the egg (figures 21 and 24)—it is mucoprotein in this species [12]. There is some reason to believe that in the rabbit a further layer of somewhat different material is added in the uterus [11]. The mucinous coat of the rabbit's egg begins to be laid down seven to eight hours after ovulation; as it is impermeable to spermatozoa, its deposition is believed to be the main factor limiting the fertile life of the eggs.

Three of the forms of egg covering described—the zona pellucida, the cumulus oophorus, and the mucin layer—are, at least in the hamster, rat, and rabbit, porous to solutes of large molecular size, and probably allow free passage to the fat-soluble vitamins, the steroid hormones, and similar substances [6].

VITALITY OF THE EGG

Compared with the eggs of oviparous animals, the eggs of marsupials and placental mammals enjoy a large measure of protection and consequently have much better chances of giving rise to normal embryos. Nevertheless, a number of conditions and chemical and physical agents are known that may interfere with or prevent the normal production and development of eggs without necessarily causing injury or death to the maternal organism.

Either egg or spermatozoon may carry lethal genes, and if the same allele is present in both cells the resulting embryo degenerates before it can complete its development. Occasionally, too, dominant lethal mutations arise, and again extensive development of the embryo is precluded. The incidence of dominant lethal mutations is often ascribed to the effects of ionizing radiations, which may constitute part of the natural background or may derive from artificial sources. X-irradiation is specifically damaging to germ-cells, and in some animals, notably mice, whole-body irradiation may sterilize the ovaries without prejudicing the animals' chances of survival [20].

Embryonic death may also be attributable to abnormalities in the complex process of fertilization. Sometimes the male pronucleus fails in its prescribed function and the female pronucleus alone provides the chromosomes for the first-cleavage spindle. When the egg divides into a 2-cell embryo, the new nuclei each contain only half the normal number of chromosomes, and development that is initiated in this way is referred to as 'gynogenesis'. Alternatively, the female pronucleus may fail, and the embryo begins development with only the paternal chromosomes: this is termed 'androgenesis'. Both forms of development seem to be inconsistent with protracted embryonic life. Sometimes, in spite of the protective devices, polyspermy occurs—two spermatozoa take part in fertilization, and so the embryo comes to have a three-fold chromosome complement. This, too, as far as is known today, precludes full normal development, and the same can be said also for the irregularities in chromosome number that follow major disturbances of oocyte maturation [9].

Many functions of the female genital tract are closely controlled by hormone balance and are affected also by the health and nutritional status of the animal, as well as by a wide range of administered drugs. Eggs and early embryos, however, have a period of free existence within the genital tract—from the time of ovulation until the implantation of the embryo in the uterus—and during this period they seem to be immune to most of these influences. Special susceptibilities do exist, however, and certain agents such as podophyllotoxin are known to be more damaging to the free-living embryo than to most other body cells [25].

The indifference of the egg to environmental change *in vivo* suggests that its vitality should be sufficient to sustain the cell when removed to other situations, and indeed there is ample evidence that this is so. In several species, eggs, as oocytes or as early embryos, can survive transfer to the genital tract of another animal [26]. Unfertilized rabbit eggs can tolerate storage *in vitro* at 10° C for as long as 96 hours [13], and fertilized rabbit eggs have often been cultured *in vitro* through cleavage to blastocyst formation. Mouse embryos have developed from morulas to

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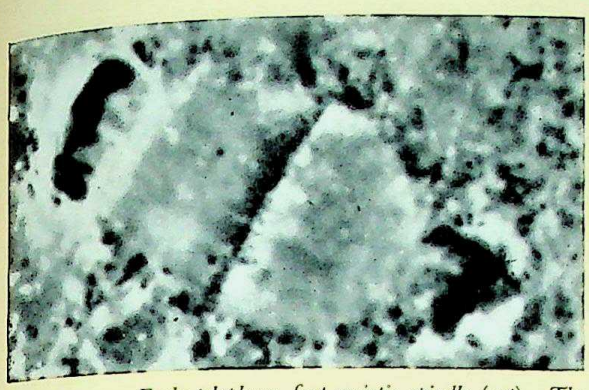


FIGURE 25 – *Early telophase, first meiotic spindle (rat). The central body is very distinct.*

FIGURE 26 – *Metaphase, second meiotic spindle (field vole).*

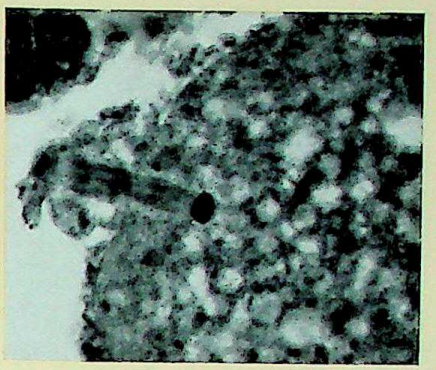


FIGURE 27 – *Late telophase, second meiotic spindle (bat).*

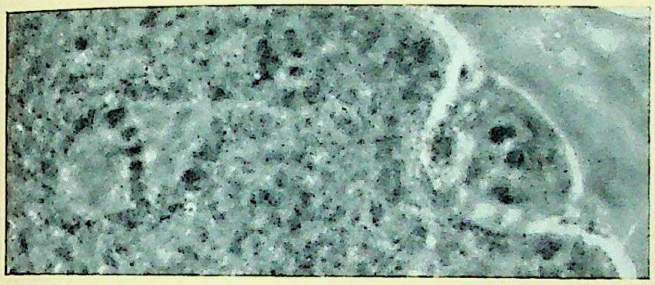
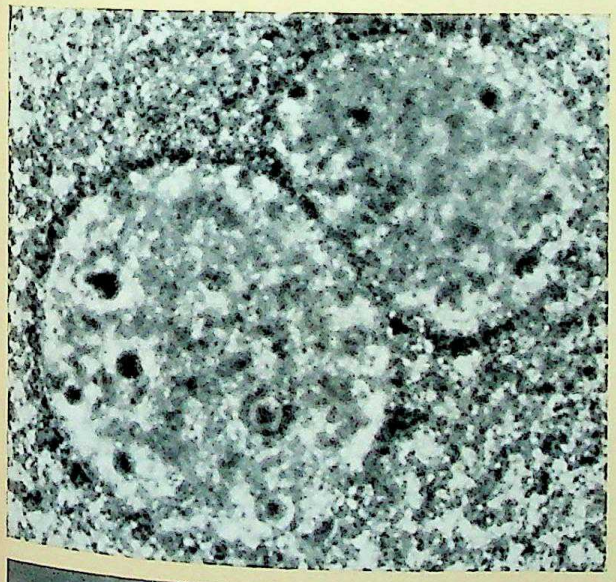


FIGURE 28 – *First polar body and metaphase second meiotic spindle (golden hamster).*

FIGURES 29 *and* 30 – *First cleavage spindle (field vole), showing X-chromosome.*



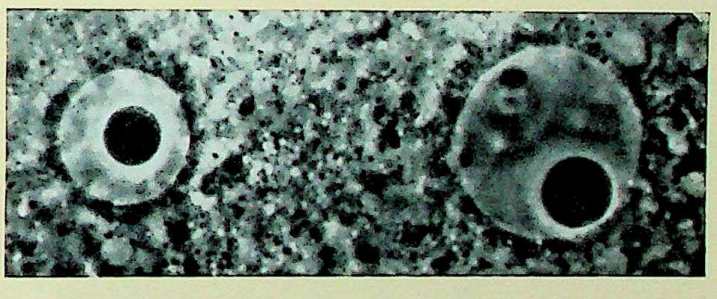


FIGURE 31 (*above*) – *Pronuclei of the Libyan jird.*

FIGURE 32 (*left*) – *Rabbit pronuclei.*

FIGURE 33 (*below*) – *Pronuclei of the golden hamster.*

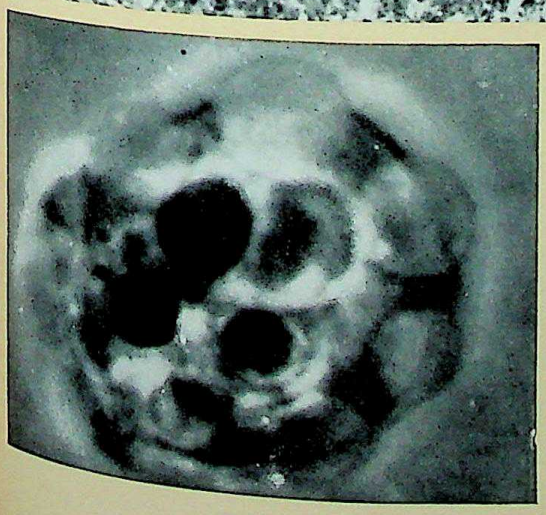


FIGURE 34 (*left*) – *Nucleus expelled from ruptured 2-cell rat egg. The apparent vesicles in the nuclear membrane are visible.*

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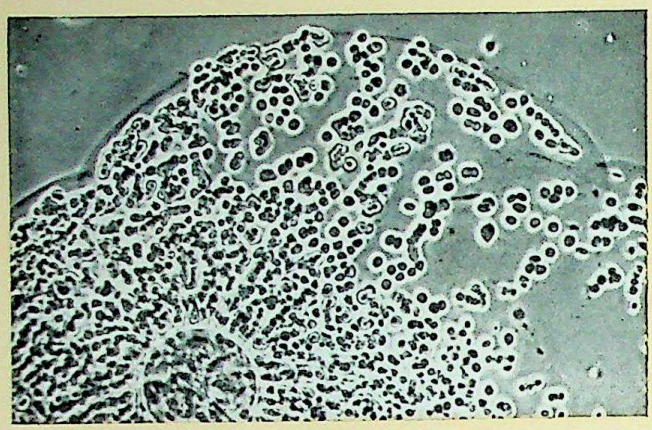

FIGURE 35 – *Rat egg surrounded by the cumulus oophorus; follicle cells embedded in a hyaluronic-acid matrix.*

FIGURE 36 – *Guinea-pig egg undergoing fertilization. Note droplets of yolk material in the cytoplasm.*

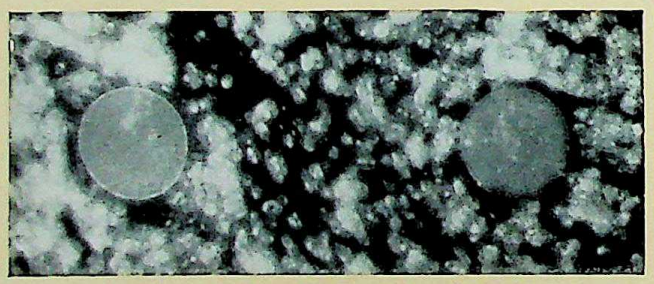

FIGURE 37 – *Loss of light refraction at the surface of a penetrated hamster egg (right).*

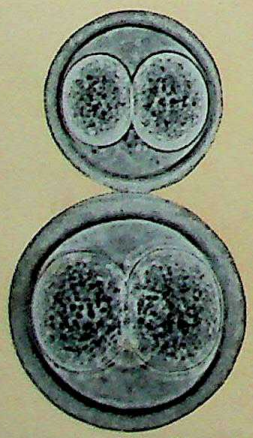

FIGURE 38 – *Normal and 'giant' eggs of the cotton-rat.*

FIGURE 39 – *Dog morula (cf. Bischoff's sketch, figure 22).*

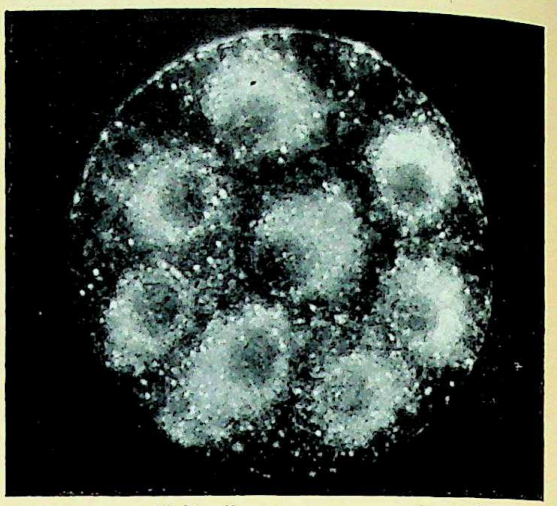

FIGURE 40 – *Eight-cell rat egg as seen by dark-ground illumination, showing distribution of granules.*

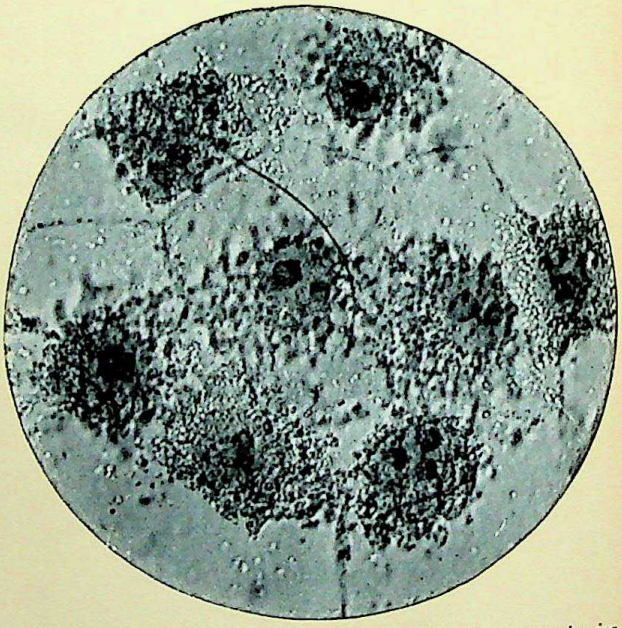

FIGURE 41 – *Ultra-violet absorption by an 8-cell rat egg, showing distribution of nucleic acids.*

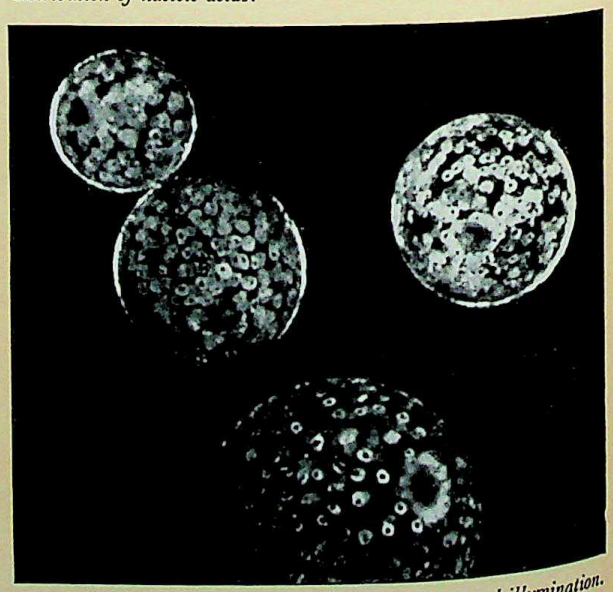

FIGURE 42 – *Dog blastocysts, as seen by dark-ground illumination.*

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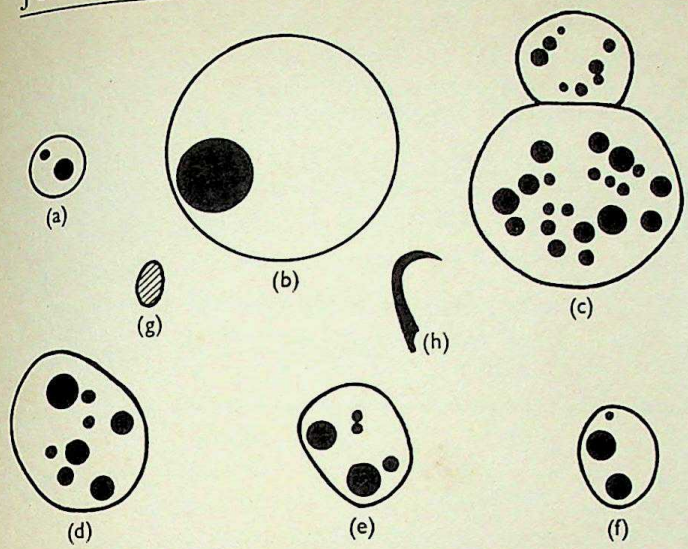

FIGURE 43 – *Relative nuclear size (rat) in* (a) *early primary oocyte,* (b) *late primary oocyte,* (c) *egg in late stage of fertilization,* (d) *2-cell egg,* (e) *4-cell egg,* (f) *8-cell egg,* (g) *follicle cell, and* (h) *spermatozoon.*

blastocysts when kept in culture in an artificial medium [24] and on transfer to a host animal have given rise to normal young [18]. Mouse eggs have also been shown capable of normal development even after being held as isolated tubal oocytes at a temperature of $-10°$ C for $3\frac{1}{2}$ hours [23], or as primary oocytes in excised pieces of ovary at a temperature of $-79°$ C for six weeks [21]. There is no doubt that, under the appropriate conditions, manipulation of eggs need involve no detrimental effects, and in view of their tolerance to storage and transfer eggs are becoming recognized as invaluable subjects for studies, not only in investigations on fertility but in cytology, genetics, and immunology.

ACKNOWLEDGMENTS

We are indebted to Mr M. R. Young for the colour photography of the fluorescent eggs (figures 1–6), which was made possible by a technique that he developed for photographing the egg sections (figures 7–17), also in colour, and for the ultra-violet photomicrograph of the rat egg in figure 41. Our thanks are due also to Dr Ruth Deanesly for the section of the bat egg shown in figure 27. Miss Heather Speer drew the diagrams appearing as figures 24 and 43. Figures 26, 29, and 30 are from the 'Journal of Anatomy'; figure 28 from the 'Journal of the Royal Microscopical Society'; and figure 37 from 'Experimental Cell Research'.

HISTOLOGICAL TECHNIQUES

Figures 7, 10. Zenker formol; Weigert H and E.
Figure 8. Flemming; Heidenhain haematoxylin.
Figure 9. Zenker; Heidenhain H and E.
Figures 11, 13. Zenker formol with acetic acid; Masson trichrome.
Figure 12. Zenker formol with acetic acid and post-osmication; Weigert haematoxylin.
Figures 14–17. Bouin; Weigert H and E.

REFERENCES

[1] AFZELIUS, B. 'Electron Microscopy of Sea Urchin Gametes'. Almqvist & Wiksell, Uppsala. 1957.
[2] ANDERSON, E. and BEAMS, H. W. *J. biophys. biochem. Cytol., Suppl.*, **2**, 439, 1956.
[3] AUSTIN, C. R. and BISHOP, M. W. H. *Proc. roy. Soc., B.*, **149**, 241, 1958.
[4] *Idem. Exp. Cell Res.* (In press.)
[5] AUSTIN, C. R. and BRADEN, A. W. H. *Aust. J. biol. Sci.*, **4**, 537, 1954.
[6] AUSTIN, C. R. and LOVELOCK, J. E. *Exp. Cell Res.*, **15**, 260, 1958.
[7] AUSTIN, C. R. and WALTON, A. In 'Marshall's Physiology of Reproduction'. A. S. Parkes (Editor). Vol. 1, pt. 2. Longmans, Green & Co., London. 1959.
[8] BEATTY, R. A. In 'Handbook of Biological Data'. W. S. Spector (Editor), p. 123. W. B. Saunders Co., Philadelphia. 1956.
[9] *Idem.* 'Parthenogenesis and Polyploidy in Mammalian Development'. Cambridge University Press, London. 1957.
[10] BLANDAU, R. J. *Anat. Rec.*, **103**, 19, 1949.
[11] BÖVING, B. G. *Cold Spr. Harb. Symp. quant. Biol.*, **19**, 9, 1954.
[12] BRADEN, A. W. H. *Aust. J. sci. Res., B.*, **5**, 460, 1952.
[13] CHANG, M. C. *J. exp. Zool.*, **121**, 351, 1952.
[14] CORNER, G. W. 'Lectures on the History of Medicine, 1926–32'. Mayo Foundation Lectures, Philadelphia. 1933.
[15] DALCQ, A. M. 'Introduction to General Embryology'. Clarendon Press, Oxford. 1957.
[16] HARTMAN, C. G. *J. Morph.*, **27**, 1, 1916.
[17] HILL, J. P. *Quart. J. micr. Sci.*, **56**, 1, 1910.
[18] MCLAREN, A. and BIGGERS, J. D. *Nature, Lond.*, **182**, 877, 1958.
[19] NEWMAN, H. H. 'The Biology of Twins'. University of Chicago Press, Chicago. 1917.
[20] PARKES, A. S. 'The Internal Secretions of the Ovary'. Longmans, Green & Co., London. 1929.
[21] PARROTT, D. M. V. and PARKES, A. S. In 'Sex Differentiation and Development'. C. R. Austin (Editor); *Soc. Endocrin. Mem.*, 7, 1959.
[22] SHARMAN, G. B. *Aust. J. Zool.*, **3**, 56, 1955.
[23] SHERMAN, J. K. and LIN, T. P. *Proc. Soc. exp. Biol., N.Y.*, **98**, 902, 1958.
[24] WHITTEN, W. K. *Nature, Lond.*, **177**, 96, 1956.
[25] WIESNER, B. P. and YUDKIN, J. *Ibid.*, **176**, 249, 1955.
[26] WILLETT, E. L. *Iowa St. Coll. J. Sci.*, **28**, 83, 1953.

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The phlogiston theory

DOUGLAS McKIE

The phlogiston theory was the first general theory of chemistry, uniting a wide variety of observations that were otherwise apparently disconnected. Although the theory was in fact erroneous, it materially contributed to the early progress of chemistry, and its importance is too often underestimated. This article describes the origins and rise of the theory, and its eventual replacement as the defects in Lavoisier's 'new chemistry' were remedied.

The phlogiston theory has always attracted those interested in the history of chemistry. There are good reasons for this: the theory arose in the modern period—that is, since 1500; it was the first general theory of chemistry; it was accepted for about a hundred years and by chemists of the eighteenth century who are still honoured as among the founders of our science; and it became inadequate, and was therefore abandoned, only about a hundred and seventy-five years ago. We may gauge its importance from the fact that as late as 1783 Lavoisier found it necessary to devote a critical study of some thirty-four pages to it in the *Mémoires* of the *Académie Royale des Sciences*; this detailed criticism, '*Réflexions sur le Phlogistique*', is comparable in historical significance to Newton's refutation of the vortex system of Descartes in the *Principia*.

The origin of the theory may in a very limited sense be detected in the speculations of the ancient Greeks on the composition of matter. Empedocles in the fifth and Aristotle in the fourth century B.C. included fire among the four elements that made up the world; that element was obviously set free in burning and often accompanied by its concomitant flame. The slight change in the theory of the chemical composition of matter made by Paracelsus in the early part of the sixteenth century involved not the abandonment of the four-element theory but the further supposition that the more immediate elementary constituents of substances, those that could be obtained by analysis, were the three 'hypostatical' principles or elements, salt, sulphur, and mercury. In this way the ancient element of fire lived on in the form of sulphur and no fundamental change had been made in the age-old beliefs about the composition of matter.

The idea of an elementary fire as a component of combustible bodies had thus been long ingrained in chemical thought; and, as we must admit, it is very naturally supposed even today, by those who are not better informed, that burning is the release of some 'fire-stuff' from a combustible.

This old and vague notion received more precise treatment from Johann Joachim Becher (1635–82), a German, born in Speyer, sometime professor of medicine in the University of Mainz but more interested in chemistry. Becher is an interesting figure. He lost his father in the Thirty Years War; as a boy he had to give lessons in reading and writing to maintain his mother, his brothers, and himself, as his family's means had been lost. He lived and worked at various times in Munich, in Vienna, in Haarlem, and in Cornwall, where there are traditions of his work. He died in 1682, probably in London—there is some evidence that he was buried in the church that is now St James's, Piccadilly. Becher published many books, and in one of these, the *Physica Subterranea* (Frankfurt, 1669, and later editions), he rejected the theory of Paracelsus. He held instead that there were three elements, air, water, and earth, although air was no more than an agent or instrument moving and impelling water and earth into 'mixts' (we would say compounds), the varying proportions of elementary earth and water occurring in these 'mixts' accounting for the diversity of substances in the world. There were, moreover, three earths: first, *terra lapidea*, fusible and vitrifiable; second, *terra pinguis*, fatty, oily, combustible, sulphureous; and third, *terra fluida* or *mercurialis*, fluid, subtle, volatile, mercurial. Metals and minerals in general were composed of these three earths in different proportions. The *terra pinguis* can readily be recognized as the old fire element in a new guise; it was presently to become, through the advocacy of Stahl, the principle or element of inflammability and to receive the name of phlogiston. It may be recalled here that, from the time of Jabir ibn Hayyan, Muslim chemistry had taught that metals were composed of two elements, namely sulphur and mercury.

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Becher's teaching made little impact on chemistry until it was adopted by Georg Ernst Stahl (1660–1734), a far more important figure. Stahl also was a German, born in Anspach; he was a student in Vienna, where he graduated M.D. in 1684; and he is remembered today for his work in biology and physiology as well as for his contributions to chemistry. On the invitation of Friedrich Hoffmann, professor of medicine in the university of Halle and perhaps the greatest German physician of his age, Stahl became the other professor of medicine in Halle (1694–1716); later he was physician to King Frederick William I of Prussia, father of Frederick the Great. He died in Berlin in 1734. Among his many books his *Fundamenta Chymiae* (Nürnberg, 1723) is chemically most important; earlier he had published a reprint of Becher's *Physica Subterranea* with an extensive commentary called *Specimen Becherianum* (Leipzig, 1703, and later editions); and some other interesting chemical books, including his *Experimenta, Observationes*, etc. (Berlin, 1731), which is especially interesting for the phlogiston theory, indicate the extent of his chemical studies.

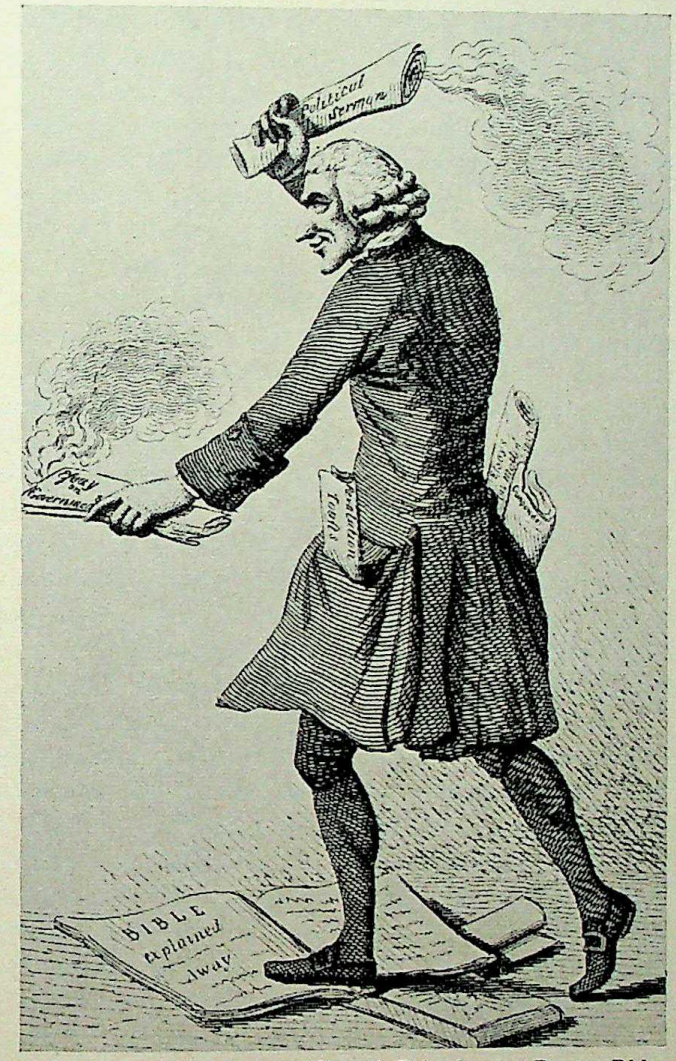

FIGURE 1 – *Lampoon of Joseph Priestley as 'Doctor Phlogiston'. The publication of this in the 'Attic Review' shows that the educated public had some acquaintance, at least, with the phlogiston theory.*

In adopting and extending Becher's views, Stahl emphasized the idea that phlogiston was released in all combustions, since it was present in all combustible bodies. Since it was contained also in metals as a common principle, it was similarly set free when they were calcined, the differences between the metals being due to the differences between their calces. Highly combustible substances, such as charcoal, oils, and fats, were rich in phlogiston, and less combustible substances had less of it. Stahl showed, moreover, that the calx of a metal could be restored to its former metallic state by heating with a substance rich in phlogiston, such as charcoal, thus demonstrating that the principle of inflammability could be transferred from one substance to another; and he had also shown that combustion and calcination were essentially similar changes. For these discoveries he was long afterwards hailed by Lavoisier as one of the patriarchs of chemistry and as one who had effected a kind of revolution in that science.

Stahl supposed also that the phlogiston set free in combustion and in fermentation passed into the atmosphere, and so air contained much of it. Air was necessary in ample quantity for combustion, because a limited amount of air could absorb only a limited amount of phlogiston. From the air phlogiston entered into the life of plants and thence into that of animals, and there was thus a kind of phlogiston-cycle in Nature, to all three kingdoms of which—animal, vegetable, and mineral—it was common.

Since sulphur on burning gave vitriolic acid, it followed that sulphur was composed of phlogiston and vitriolic acid; for this Stahl produced what he considered to be an experimental demonstration of the correctness of the theory. Sulphur on combustion gave vitriolic acid; with an alkali, salt of tartar (potassium carbonate), he converted the acid into vitriolated tartar (potassium sulphate); he then heated this with powdered charcoal (largely phlogiston) and, on treating the solid product with vinegar, he obtained milk of sulphur. By this series of changes he had restored to the vitriolic acid the phlogiston removed from it in the first reaction and had thus reconstituted the sulphur.

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Such was the phlogiston theory when Stahl died in 1734. In the fifty years that followed it spread outwards from Germany and was accepted by the chemists of Europe—by Black, Priestley, Cavendish, Scheele, Bergman, Macquer, Guyton de Morveau, Berthollet, and Fourcroy, to name only a very small number of them. In those fifty years chemists made many discoveries, particularly the discovery of 'airs', as the gases were then called. To these the phlogiston theory proved most accommodating. When Cavendish, for example, isolated 'inflammable air' (hydrogen) in 1766, he was satisfied that it came from the metals and not from the acids with which the metals had reacted; and later many chemists, including Cavendish for a time, regarded this 'inflammable air' as the phlogiston released from the metals. Still later, in 1783, further new, strong experimental evidence was afforded in favour of the theory, when Priestley found that 'inflammable air' passed over heated metallic calces restored them to their former state of metals. Phlogiston in an almost pure state had been restored to the calx and had reconstituted the metal.

The isolation by Priestley in 1774–75 of the new 'air' that was later called oxygen was one of the most significant discoveries in this period; it was soon enfolded within the phlogiston theory. When Priestley noted that this new 'air' enhanced the burning of a candle and other combustibles and that it maintained animal respiration much longer than common air, he quickly pointed out that common air was constantly being contaminated with phlogiston released from fires, fermentation, putrefaction, and respiration, whereas the properties of the new 'air' clearly showed it to be uncontaminated with phlogiston, and so he named it 'dephlogisticated air'.

In combustion and respiration in common air, both processes ceased after a time, leaving a residue no longer fit to maintain them; in respiration and in certain combustions it was necessary to remove by milk of lime or lime-water the 'fixed air' (carbon dioxide) that Joseph Black had differentiated from common air in 1754–56; but in all cases the final residue was supposed to be common air saturated with the phlogiston given off in combustion or in respiration, and so it was named 'phlogisticated air' (nitrogen).

While the phlogiston theory readily explained these new facts, there was one long-established experimental observation in apparent contradiction with it, namely the gain in weight of metals on calcination when, according to the theory, phlogiston was set free. Although the principle of the conservation of mass in chemical change was not yet explicitly formulated, gain in weight with concurrent loss in substance was not acceptable in chemical thought. Many ingenious explanations were put forward to explain this apparent anomaly. Guyton de Morveau supposed that phlogiston was lighter than the lightest substance known and that it therefore buoyed up the metals of which it was a component; they became heavier when it was set free in calcination. There were some who supposed that phlogiston had a negative weight, being repelled from the centre of the Earth towards the circumference; whereas other kinds of matter gravitated towards that centre, phlogiston levitated from it.

In a series of researches that began in the 1770s Lavoisier showed that the gain in weight of metals on calcination could be quantitatively accounted for by their combination with a part, about one-fifth, of the common air; that this part, to which he subsequently gave the name of oxygen, was similarly active in combustion and in respiration; that the other part, about four-fifths (later known as nitrogen), was inactive in all three processes, extinguishing fire and asphyxiating life; and that, when combustion took place in oxygen, there was no residue of 'phlogisticated air', the oxygen being consumed 'to the last bubble'. (*jusqu'à la dernière goutte*). His work failed, however, to convince his contemporaries for almost ten years; and when he attacked the phlogiston theory in 1783 he was without any supporter. There were good reasons, of course, why the chemists of that time did not wish to abandon their theory, which was a general systematizing theory of chemistry, for a new one that was limited in its application. One of these reasons was very simple. It concerned the combustion of 'inflammable air'. According to Lavoisier's theory, all combustion was combination with oxygen, but attempts both by himself and others to isolate a product of this particular combustion failed. While neither theory was of value on this important point, the phlogiston theory could at least satisfactorily explain the difference between the products of the reaction between an acid and a metal, when 'inflammable air' was evolved, and of the reaction between the same acid and the calx of that metal, when, of course, 'inflammable air' was not evolved. To the phlogiston theory a metal consisted of its calx united with phlogiston, and 'inflammable air' was produced in the first reaction by the realease of that phlogiston; there could be no evolution of

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'inflammable air' in the second reaction because the calx was the residue of the metal after it had lost its phlogiston. For this difference Lavoisier could give no explanation; the composition of acids was unknown, and Lavoisier regarded them as oxides; the composition of water was likewise unknown.

In June 1783, however, Lavoisier heard from Blagden, then on one of his frequent visits to Paris, that Cavendish had burnt a mixture of 'inflammable air' and 'dephlogisticated air' and that he had obtained water from this combustion. Lavoisier appears to have realized the significance of this observation; he made a crude experimental verification of it at once and advanced the explanation that water was a compound of these two gases. The difference between the two reactions referred to in the preceding paragraph could now be explained, since water could be regarded as taking a part in them. In the former, the water could be considered as decomposing, its 'inflammable air' being evolved and its 'dephlogisticated air' or oxygen combining with the metal to give the calx (the term oxide had not yet been coined), which then united with the acid to produce the salt; in the latter reaction it was a simple case of the calx combining with the acid to give the salt. Lavoisier began to gain some supporters, for a fundamental difficulty in his theory was now resolved.

There were, however, other difficulties, far from trivial, which were more adequately explained by the phlogiston theory. For instance, there appeared to be two kinds of 'inflammable air', which Lavoisier differentiated as 'light inflammable air' (hydrogen) and 'heavy inflammable air' (carbon monoxide). The composition of the latter was not understood; it gave 'fixed air' or carbonic acid on burning. It proved a baffling problem for the new theory, but it was explicable in terms of phlogiston. Priestley himself made considerable use of it. He had obtained 'inflammable air' (carbon monoxide) when he heated finery cinder (iron oxide) with charcoal. He argued that, since the new theory considered 'inflammable air' as a component of water, it could be produced only in a reaction where water was present; and, he pointedly added, the new theory itself excluded water from the composition of these reactants, taking finery cinder to be an oxide, containing only iron and oxygen, and admitting no water in the composition of charcoal, which was a substance produced at the highest degree of heat. The old theory, on the other hand, regarded finery cinder as having imbibed water in place of its phlogiston and it also supposed that water was a constituent of all 'airs', so that the 'inflammable air' was produced by the union of the water from the finery cinder with the phlogiston from the charcoal. This reaction remained incomprehensible to the new theory until Cruickshank, in 1801, showed that Lavoisier's 'heavy inflammable air' was not hydrogen but an oxide of carbon, which he named 'gaseous oxide of carbon'. This interpretation was slowly accepted, although it failed to convince Priestley that he was wrong; he remained an adherent to the phlogiston theory until his death in 1804.

There were many attempts to adjust the phlogiston theory to the new discoveries in chemistry, particularly by Gren in Germany, and much ingenuity was spent for this purpose. In general, these were concerned with the problem of the heat and light evolved in combustion, which effects were not satisfactorily explained on Lavoisier's theory. There had been many earlier adjustments of the theory: Kirwan had identified phlogiston with 'inflammable air' and Macquer had considered it to be the matter of light; but, although chemists were accustomed to depart from the original theory as propounded by Stahl, it seemed that the most satisfactory way of explaining what Lavoisier's theory did not explain was to suppose that a combustible contained phlogiston and that oxygen gas contained caloric or the matter of heat, so that in the process of combustion, while the oxygen combined as usual with the combustible, the phlogiston from the latter combined with the matter of heat from the oxygen to give the fire and light that were so often the products of ignition. In one form or another the phlogiston theory survived in the background of the chemical thought of the early nineteenth century. This should cause us no surprise; for it was still customary, and long remained so, in chemistry to include the imponderables, heat and light, among the elements of which matter was composed, and it was fundamental in physics, for good reasons, to consider that heat was material. The difficulties inherent in the new chemistry were not resolved until the mid-nineteenth century, when the nature of heat had become clear, and when energy, and its changes and transformations, were at last understood. It is interesting to observe that the great chemists of the eighteenth century did not abandon the phlogiston theory as soon as an alternative was produced, but made many skilful adjustments of that theory to fit, for as long as possible, the changing pattern of discovery.

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Crystalline rocks and the passage of time

J. SUTTON

The determination of the order of the strata occurring in the Earth has been accomplished, in the main, by the use of the fossil-bearing sedimentary rocks. This method cannot be applied to the Pre-Cambrian rocks, which are devoid of usable fossils, nor to the crystalline rocks generally. This article describes methods that have been devised for such rocks.

Since the early nineteenth century, when William Smith first showed how the relative ages of sedimentary rocks could be determined from the fossils they contain, geologists have been elaborating a stratigraphical succession covering geological time from the Cambrian to the present day. Once the position of a rock within this stratigraphical column has been established, the geological events that have left a record in that rock can be placed more or less precisely in their correct chronological setting. In this way the distribution of land and sea, the position of the principal mountain chains, and the changes in climates in the past have been gradually elucidated. It is, naturally, geological events that have taken place at the surface of the Earth that are best recorded in the sedimentary rocks and in the interbedded volcanic rocks, although these rocks also provide indirect evidence by which earth movements and igneous activity originating at depth may be dated. Indeed, it is true to say that the greater part of our knowledge of the distribution of earth movements through geological time since the Cambrian, when usable fossils first appeared, comes from the evidence supplied by sedimentary rocks.

Such evidence, however, is fragmentary and hard to come by, for it requires that one should find datable deformed rocks covered by slightly younger datable rocks unaffected by the deforming movements. The age of an intrusion can be approximately determined in an analogous manner; thus the Shap 'granite' of north-west England was formed after the Silurian, since it cuts beds of that age, and before the time when the overlying Lower Carboniferous beds were deposited. Evidence of this kind is even more difficult to find in the more highly metamorphosed parts of mountain chains and is, of course, totally lacking in the unfossiliferous Pre-Cambrian.

The classical methods of stratigraphy need to be supplemented if one is to comprehend the history of the changes that have gone on at depth within the crust of the Earth throughout geological time. The three great groups of events concerned in such changes are the arrival of igneous material, the production of metamorphic rocks, and the deformation of the crust.

The absolute dating of the crystalline rocks in which such changes are recorded has been possible since Rutherford saw that the breakdown of radioactive minerals offered a way of measuring the time that had elapsed since they were formed. A quite different approach has been the attempt to establish the relative ages of assemblages of minerals in metamorphic rocks, or of successive sets of geological structures formed by earth movements. This can be done by detailed examination of the anatomy of metamorphic terrains. A third possibility consists of dating events which took place at depth by considering the effects they produced at the surface on sedimentary rocks whose age can be established by classical means. It is with applications of the second method that we shall be mainly concerned in this article, but first we may consider some matters connected with absolute age determinations.

THE ABSOLUTE AGES OF ROCKS

The techniques so far used, such as the measurement of the uranium : lead, rubidium : strontium, or potassium : argon ratios are tedious and costly, and it is plain that each determination should be made to yield as much information as possible. A. Holmes [1] and more recently K. I. Mayne, R. St J. Lambert, and D. York [2] have shown that curves giving the length of time represented by any part of the stratigraphical table, from the Cambrian on, can be drawn from comparatively few measurements. Mayne and his co-workers employed 17 measurements of material which could be placed in the conventional stratigraphical table, and used these measurements to show the absolute ages of the geological divisions in question. The material came from widely separated parts of Europe and America. Pre-Cambrian rocks naturally could not be dealt with in this way,

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for there is as yet no purely geological means of placing Pre-Cambrian rocks in a chronological sequence that would be valid over so large a region. The dating of the Pre-Cambrian has largely been achieved by mapping out the major structural divisions in each area, and by finding the age of minerals believed to have formed when the major structures same into being during the succession of Pre-Cambrian periods of orogeny[1].

The recognition of the sequences of events which occurred during such an orogeny and which are recorded in the crystalline rocks, and their correlation so as to produce a world-wide geological succession extending back into Pre-Cambrian time, is a fascinating task on which many are now engaged. Much has already been done, and some questions, such as the distinction between granites formed at the height of the mountain-building movements and those formed in the closing stages, are now reasonably well understood in a qualitative way. An important advance is the recent work in California by Evernden, which, for the first time, shows how much time elapsed while a succession of granites was intruded during a single cycle of mountain-building. This result was obtained on material from a geologically young mountain chain, but it is to be hoped that, as techniques improve, similar work will be undertaken on the granites of the older chains. It is of interest that Evernden was able to confirm the sequence of intrusion that had already been deduced from observations in the field, and that the absolute dating confirmed in every case the succession indicated by geological reasoning.

THE GEOLOGICAL DATING OF CRYSTALLINE ROCKS

We may turn now to some examples of sequences of events deduced on geological grounds from observations made in crystalline rocks in Scotland, where few determinations of absolute age have been made. In Scotland there are preserved fragments of at least three mountain chains. In the Outer Hebrides and along the north-west seaboard of the mainland the Lewisian gneiss retains a record of two Pre-Cambrian orogenies, and to the east there are the extensive outcrops of the Moine and the Dalradian Series which were folded and metamorphosed during the Caledonian orogeny and which form part of a chain of crystalline rocks extending from Norway to western Ireland. The detailed maps published by the Geological Survey, and the work which numerous investigators are carrying out at the present time, show that for each of these orogenies there can be made out a succession of phases during which rocks were metamorphosed, deformed, or cut by intrusions. Some examples may be more helpful than a general discussion.

The Lewisian rocks along the west coast occur in two rather different conditions [3, 4]. In certain tracts, for example between Scourie and Gruinard, the gneisses frequently strike to the north-east and are commonly very highly metamorphosed; the gneissose assemblage as a whole is cut by fresh dolerite dykes. In other districts, such as that between Loch Laxford and Cape Wrath, the dolerites have also been metamorphosed, and both they and the surrounding gneisses have been affected by renewed earth movements, with the result that the gneisses now strike north-west; they are invaded by numerous granites and pegmatites which can be shown to be later than the dolerites.

It would appear that this arrangement is the product of two separate periods of mountain-building. During the first period, which has been called the Scourian, metamorphism occurred and the rocks acquired their north-easterly strike. Then followed a phase when dolerite dykes were intruded. Subsequently parts of the Lewisian were affected by a second, or Laxfordian, orogeny during which further metamorphism and deformation took place. Those parts of the Lewisian which escaped the effects of this later period remain in the condition produced by the earlier orogeny. The key to the geological history is provided by the swarm of dolerite dykes intruded between the two movements; the dykes are unaltered where the Scourian orogeny alone has affected the rocks, but are metamorphosed where the effects of the Laxfordian orogeny have been superimposed on those of the Scourian.

Two orogenies of Pre-Cambrian age have been identified on very similar evidence by Noe-Nygaard [5] in west Greenland, and comparable examples of repeated metamorphism have been reported from the Alps, where rocks first metamorphosed during the Palaeozoic Hercynian orogeny have been re-metamorphosed during the Alpine movements of the Tertiary Period. Thus, in the Silvretta region of the eastern Alps a swarm of dolerites was intruded between the two movements just as in the previous examples [6].

An interesting picture emerges if one examines

[1] Orogeny is the phase in mountain-building during which the accumulated sediments are compressed, giving rise to folds and faults.

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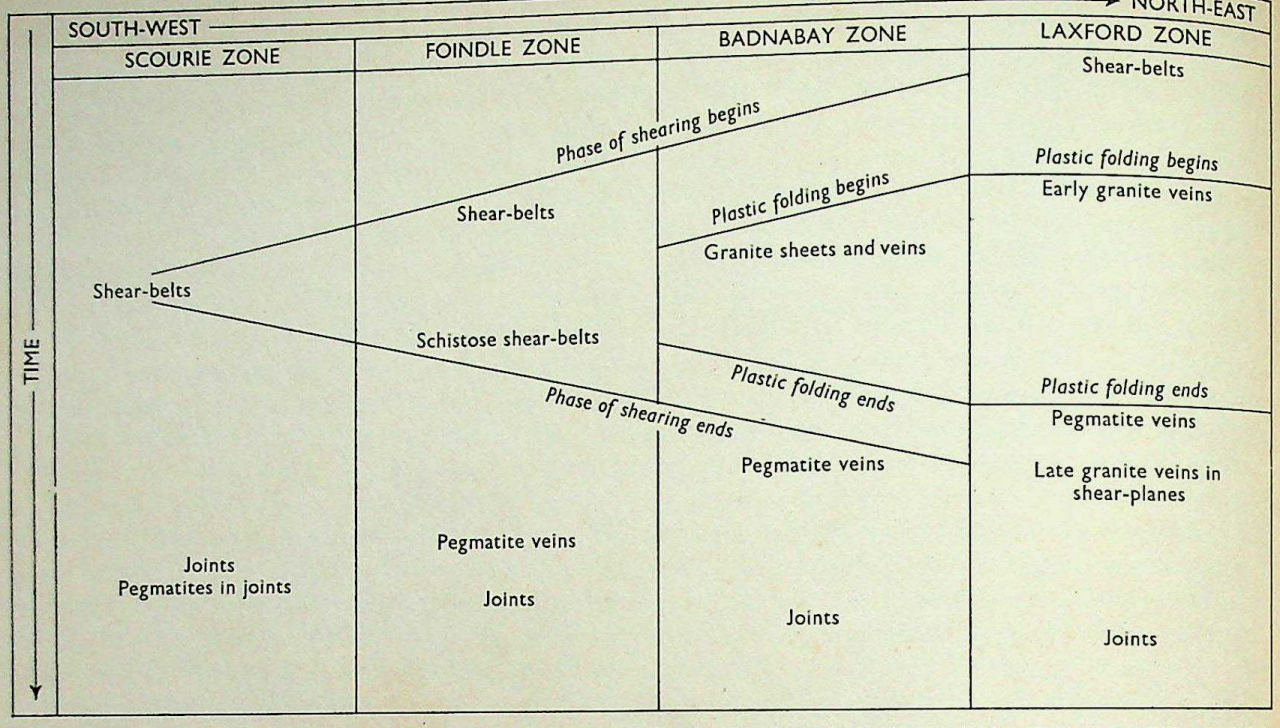

FIGURE 1 – *Sequences of events established in Lewisian rocks near Loch Laxford, Sutherland.* (*After Sutton and Watson* [4].)

the Lewisian of western Scotland near the margin of an area affected by the later Laxfordian orogeny. The results of such an examination are summarized in the accompanying table (figure 1). Each column records a sequence of events made out in one zone—the zones are 12 km wide in all and are arranged in series from the least altered (in the south-west) to the most altered (in the north-east). Laxfordian movements, metamorphism, and migmatization were most pronounced in the Laxford zone in the north-east and progressively diminished towards the Scourie zone some 12 km further south-west. The train of events set in motion by the Laxfordian orogeny did not begin at the same time in every place, but it seems that the Laxfordian metamorphic front was diachronous, in that it apparently worked its way southward through the crust and then retreated again to the north. The Scourie zone had the simplest history and the Laxford zone the longest and most complicated. In each zone the onset of the movements was marked by the formation of shear-belts—long strips of rock in which the gneisses were ground down while wedges of crystalline rock moved past. As the metamorphism developed, shearing gave place to folding in the two most northerly zones, while movement along shear-belts was still taking place further south, where the metamorphism was less intense. Towards the close of the movements, shearing once more occurred everywhere. Granitic rocks of various kinds had begun to appear during the phase of plastic movement. In the north-eastern zones, shearing movements were still continuing when the last of these granites or pegmatites were formed, but at Scourie the movements had already stopped when the latest pegmatites were intruded. The variations across the relatively narrow zones of the Loch Laxford region show how rapidly the time relations of igneous activity, metamorphism, and deformation may change, and illustrate the complexities of the histories recorded in crystalline rocks.

A. Holmes, H. A. Shillibeer, and J. T. Wilson [7] have determined the age of felspars from Laxfordian pegmatites by the potassium: argon method and found it to be 1090 ± 70 million years. In view of later findings that felspars during their lifetime may lose up to 30 per cent of the argon resulting from radioactivity [8], the age of the Laxfordian orogeny is likely to be rather greater. The Lewisian, with its two well-demarcated structural patterns, would appear to be an ideal formation in which to relate absolute ages to time sequences established on structural and metamorphic evidence. No successful Scourian determination of age has been published up to the time of writing. Holmes and his colleagues have compared the sequence seen near Loch Laxford with sequences in rocks for which similar ages had been

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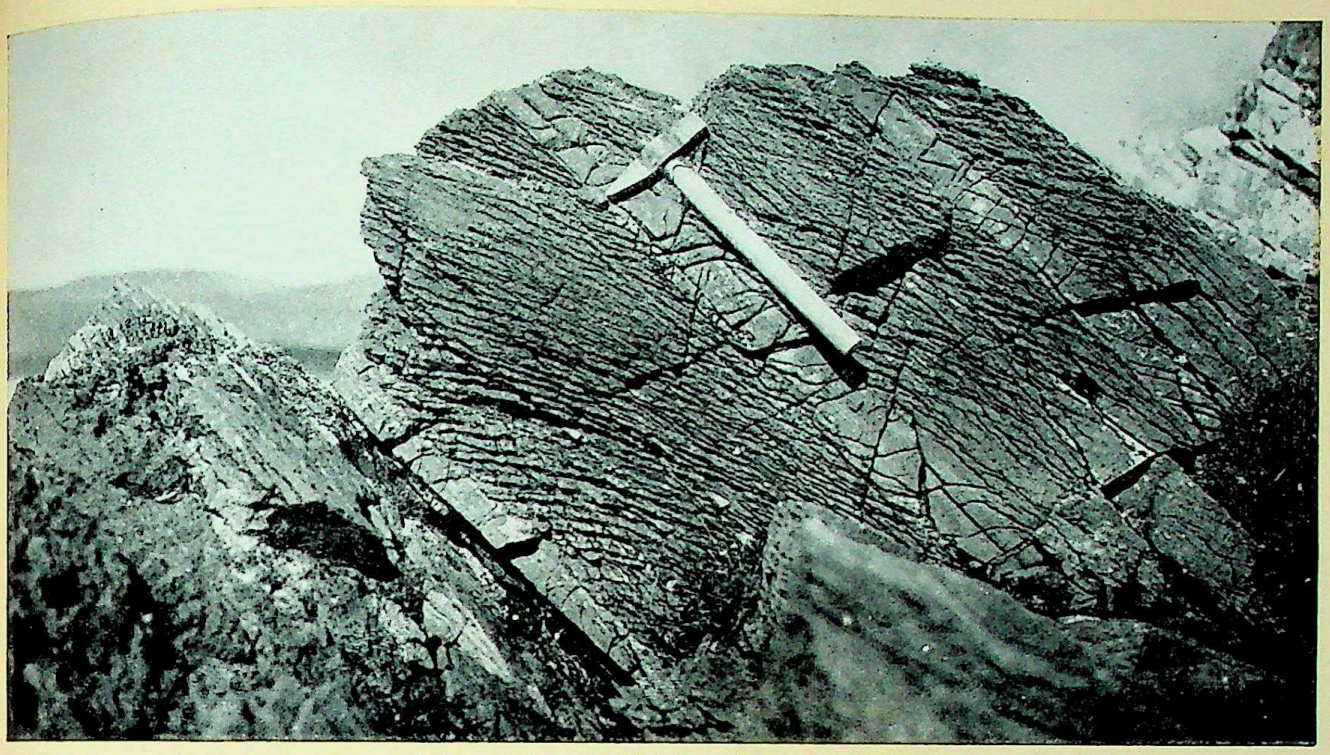

FIGURE 2 – *Cleavage planes in folded argillaceous schists, Ross of Mull.*

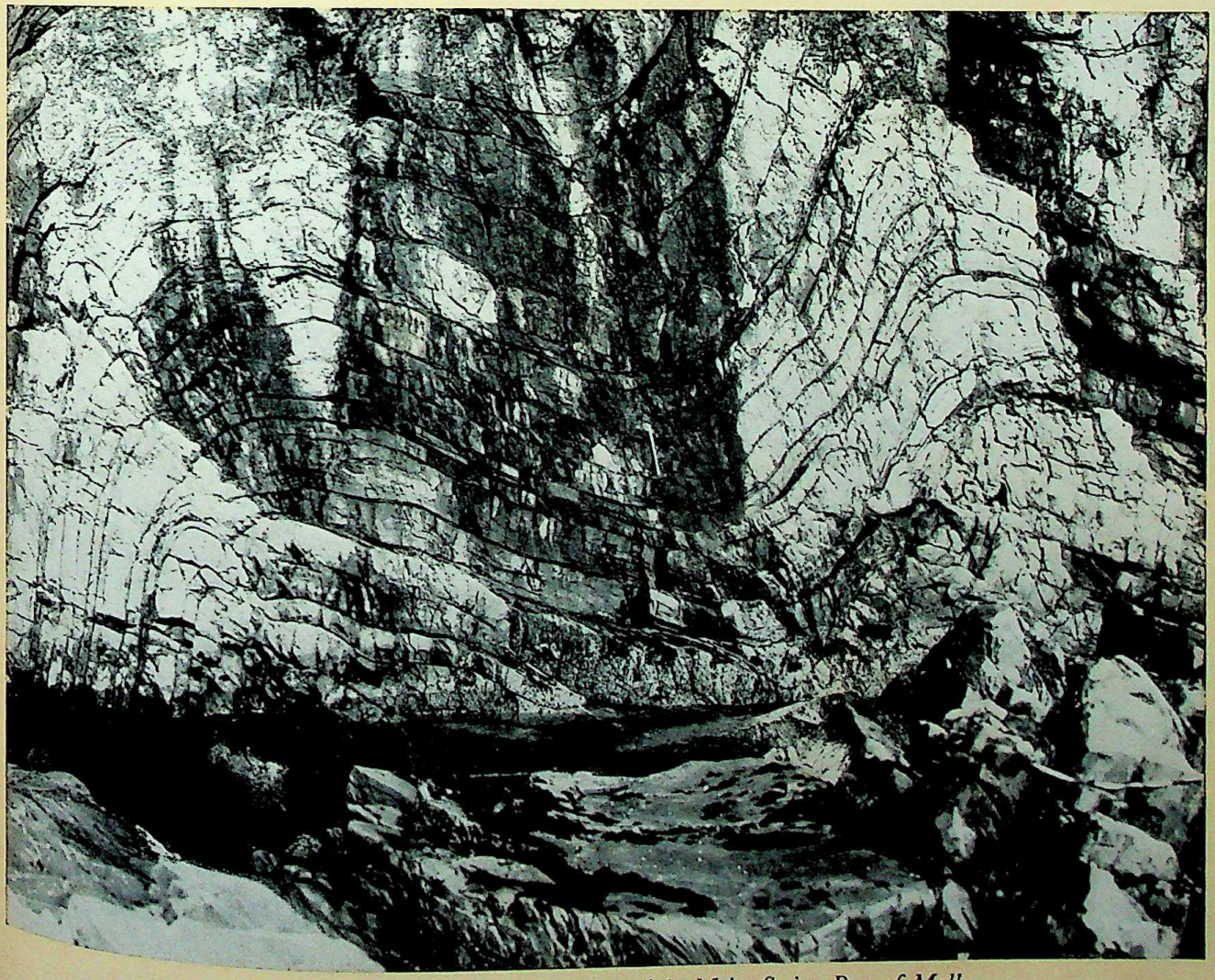

FIGURE 3 – *Folded siliceous granulites of the Moine Series, Ross of Mull.*

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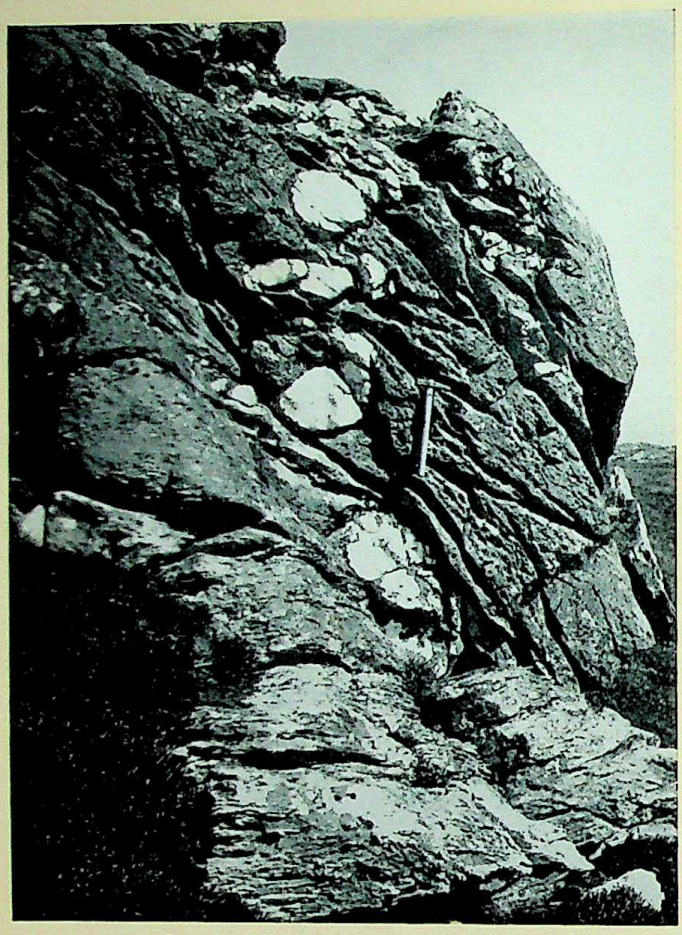


FIGURE 4 – *Quartz rods in the cores of folds. Each mass is elongated parallel to the axes of the folds. The outcrop is 2 metres high and shows the quartz rods in cross-section. Figure 6a shows similar quartz masses. Ben Hutig, Sutherland.*

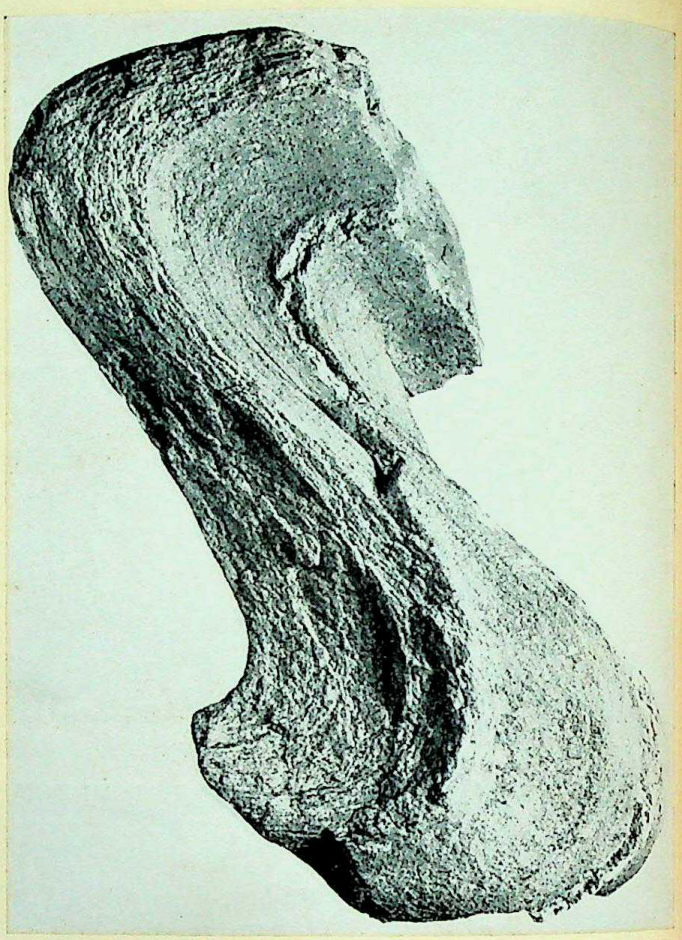
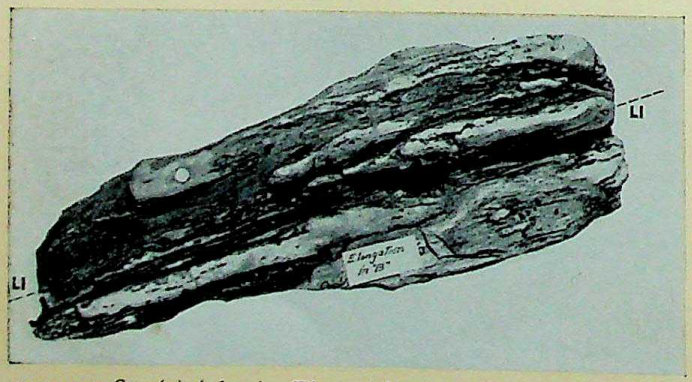


FIGURE 5 – *Siliceous rock from Unst, Shetland, showing effects of repeated deformation: a lineation, seen as a faint striation, has been twisted during folding associated with the third metamorphic episode described in the text. The specimen is approximately 40 cm in length.*



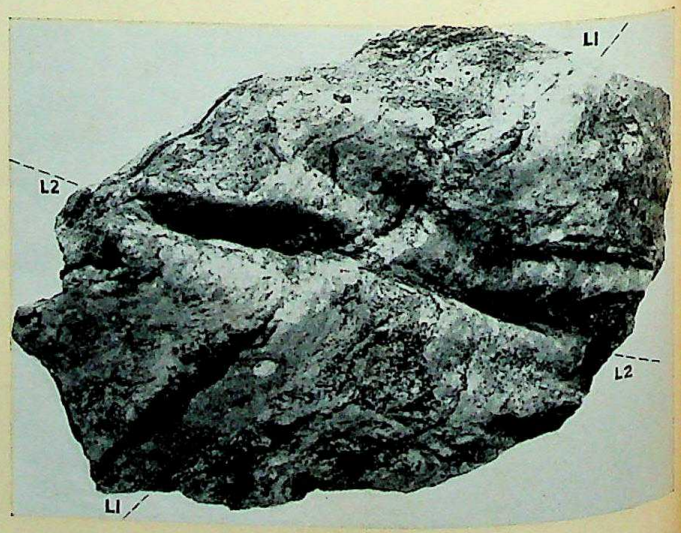


FIGURE 6 – (*a*) (*above*). *Elongated masses of quartz in a lineated rock. The structures are parallel to the local fold axis. The rock has been folded once. The specimen is 30 cm in length.* (*b*) *Here the rock has been folded twice. Quartz rods and lineations formed in an earlier period of folding (L1) run from bottom left to top right, and have been twisted in a later period of folding, during which the folds marked L2 were formed. The specimen is 25 cm in length.*

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determined in south Harris and in Arendal, southern Norway.

THE RECRYSTALLIZATION OF METAMORPHIC ROCKS

The dating of crystalline rocks involved in two orogenies has been approached from a rather different angle by G. L. Davis, G. W. Wetherill, G. R. Tilton, and C. A. Hopson [9]. They investigated minerals from the Baltimore Gneiss, a rock group in the Appalachians whose age has been a matter of discussion. They found the zircon to be 1100 million years old, using the uranium : lead ratio, and the felspar microcline to be 1200±200 million years old. Biotite gave ages of 310 million years from both the rubidium : strontium and the potassium : argon ratios. From these results they concluded that the Baltimore Gneiss had originally been formed in Pre-Cambrian times, about 1100 million years ago, and that it had been re-metamorphosed during the Palaeozoic earth movements and metamorphism about 300 million years ago, when the biotite formed. That different minerals of a single rock should have crystallized at such widely separated geological times may seem surprising. It appears to accord well, however, with the geological history of the Baltimore Gneiss, as reported by those who have investigated it in the field.

Evidence suggesting such an occurrence in Britain has been available since early this century, though no measurements of absolute age have yet been made on the material. Over fifty years ago, officers of the Geological Survey described [10] the occurrence of radiating clusters of the mineral hornblende in Lewisian rocks which had been involved in the later Caledonian movements, and demonstrated that the present form of the hornblende dated from Caledonian times. Recently it has been possible to carry this argument a stage further, and to show in which of several phases of Caledonian movement such hornblendes recrystallized. These hornblende-bearing gneisses are good examples of metamorphic rocks in which an early arrangement of minerals has been partially superseded by a new arrangement. Such rocks can be described as polymetamorphic: they are formed not only by the superposition of metamorphoses occurring in independent periods of mountain building, but also during the successive phases of a single mountain-building cycle. The mapping of sequences of mineral assemblages and, still more, the mapping of successions of geological structures, offers a way of establishing the metamorphic history of crystalline rocks produced during such successive phases. Investigations of this kind have been made for a long time, certainly since the start of this century, when B. N. Peach and others were interested in the orientation of minerals seen in crystalline rocks in the Scottish Highlands. In the last twenty-five years this work has received new impetus, from investigation of the micro-fabric of rocks and from observations made on deformed structures.

CRYSTAL ORIENTATIONS IN DEFORMED ROCKS

When new minerals develop in metamorphic rocks while these rocks are being deformed, the mineral grains are often oriented systematically in response to the deforming pressures (figure 2). A familiar example is provided by the manner in which the crystals of the platy minerals of a slate are arranged along the planes in which the slate cleaves. When it was discovered by B. Sander and W. Schmidt that approximately equidimensional minerals were also arranged systematically in metamorphic rocks, it was clear that the orientation was controlled in such instances by some internal property of the crystal lattice and not by the external form of the crystal grain. It has been found, for example, that in folded siliceous metamorphic rocks (figure 3) quartz particles may commonly be arranged so that their crystallographic 0001 axes fall in a plane normal to the axes of the visible folds. The reason for this is not yet clearly understood, but the existence of the phenomenon is now well established.

Quartz grains in siliceous rocks of the Moine Series in Scotland were found to be arranged in planes normal to a visible striation or lineation by F. C. Phillips [11], and subsequently he and other workers such as C. B. Crampton [12] have shown that many of the other rock-forming minerals in these rocks are systematically arranged. The fabric—that is, the arrangement of minerals—and the lineation also frequently bear a simple relationship to much larger structures, such as folds several kilometres in wavelength [13, 14]. At Scardroy in Ross-shire, for example, where the major folds run south-south-east, the most widely developed lineation (figure 6) follows this direction and the quartz grains have their axes arranged in a plane normal to this lineation. Similar relationships between microscopic fabric and large structures have now been established in many parts of the Scottish Highlands. These allow correlations to be made between mineral

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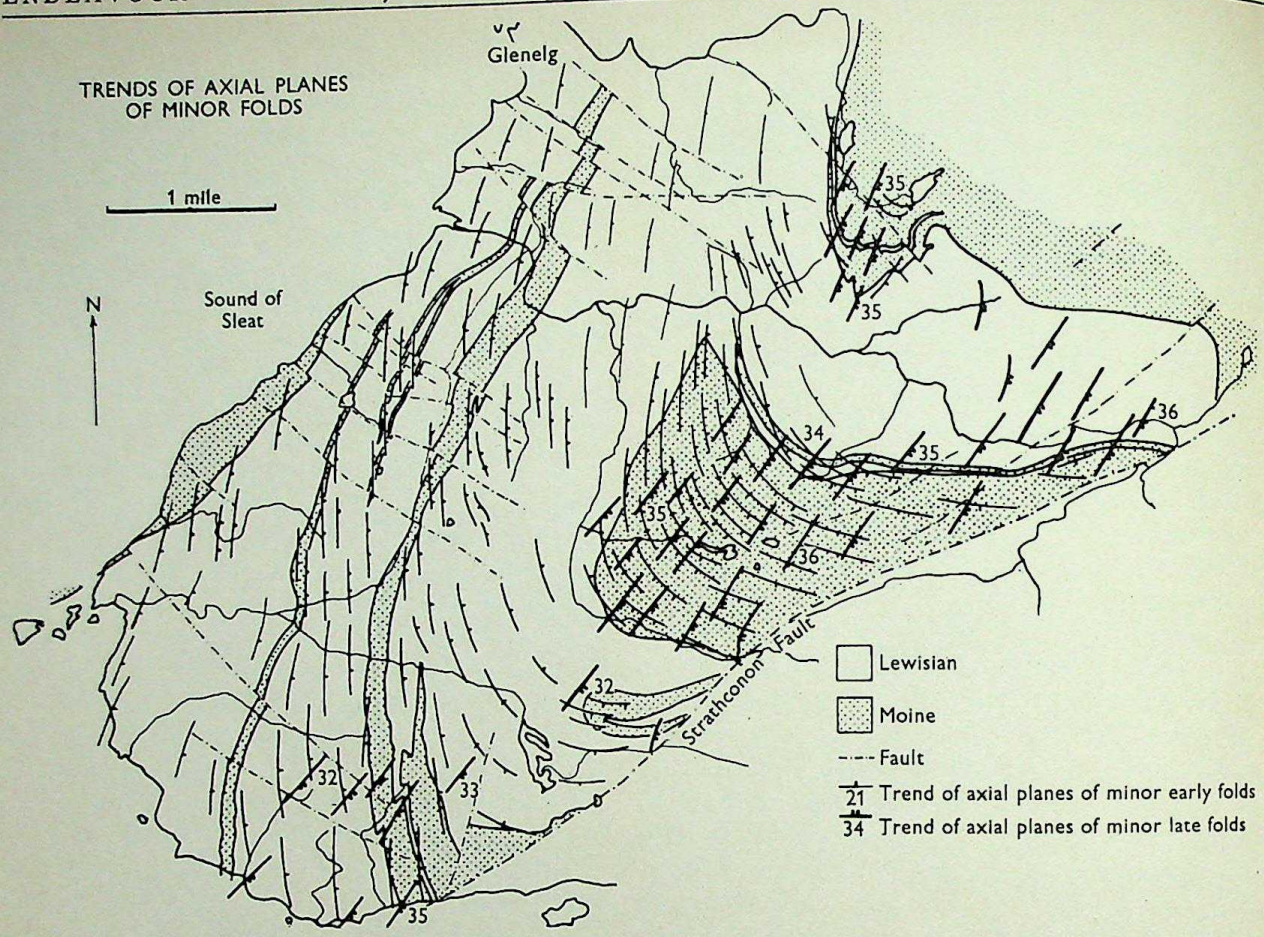

FIGURE 7 – *Map showing how planes of cleavage formed during one period of folding have been deformed during later movements which in turn produced further planes striking north-east.* (*After J. G. Ramsay* [16].) *Glenelg, Inverness-shire.* (*Figures 1 and 7 are reproduced by courtesy of the Geological Survey.*)

assemblages many kilometres apart, when it can be shown that both are associated with a single large structure that can be followed across the intervening ground. The most useful structures are the large folds, the smaller structures such as folds a few metres across, and the cleavage planes associated with them.

Recently, work on such structures has shown that at least three sets of movements affected the metamorphic rocks in parts of the Moines, and that one set is superposed on another. L. E. Weiss [15] gives a bibliography of recent papers on superposed structures. Successive movements are common in mountain building, and it has long been recognised that folds running in more than one direction and dating from more than one period were present in the Moine Series of Scotland. The new work breaks fresh ground in demonstrating how earlier structures are deformed by later ones, and how in turn the later structures are influenced by the earlier. Over much of central Ross-shire the rocks remain in the condition to which they were brought during the second of the three periods of folding which affected the rocks during the Caledonian orogeny. Locally, structures and minerals formed during the earliest period can be detected, and as these are traced into ground affected by the later movements, the folds, lineations, and cleavages formed in the first set of movements become distorted by the later structures which cut sharply across the earlier (figures 6, 7). When the microfabric is investigated, it becomes clear that the individual grains gradually take up new orientations related to the new structures. A third set of Caledonian structures is developed in much of the ground near the borders of Wester Ross and Inverness, and here, too, the superposition of new structures on old can be seen [14, 16, 17].

By linking metamorphism and structure one is thus able to distinguish three generations of minerals, to map out the domain of each on the ground, and to use the chronological succession so established to investigate new problems. One can, for example, find how metamorphism varied at any one place with the passage of time [16,17],

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or how it varied across the region during an individual phase of folding. J. G. Ramsay showed [16] that, close to the north-west margin of the chain at Glenelg, there was little recrystallization in rocks affected by the third set of movements, whereas recrystallization was taking place in the Monar and Orrin districts [14, 18] at the time of these movements, and granite sheets were intruded along their axial planes after the folds had formed. In the two latter districts, which are some 25 km within the mountain belt, the conditions of metamorphism appear to have changed only very slightly during the movements, whereas near the edge of the chain the metamorphism was clearly waning as the third set of folds developed.

The island of Unst in Shetland clearly exemplifies repeated metamorphism accompanied by striking mineralogical changes [19]. Examination of the structures provides striking confirmation of the three-fold metamorphic sequence found by H. H. Read in the west of Unst. There is a strong lineation present in staurolite-kyanite-garnet gneisses formed in the first episode. Both this lineation and the crystallized quartz rods are twisted about new axes on the margin of the domain where a second episode can be detected. Where the new minerals such as chloritoid, characteristic of the second metamorphic episode, are well developed, the earlier structures have been destroyed and the new folds and lineations become dominant. Read recognized a third set of metamorphic minerals along a belt of intense deformation down the centre of Unst, and these also are marked by a characteristic set of structures (figure 5).

The successions of events discussed here suffer from several defects as potential geological time scales. There is the likelihood that either deformation or metamorphism may be diachronous and there is the uncertainty of the time interval between successive phases, which may themselves be prlonged. Nevertheless, the methods provide evidence concerning the relative time relations of deformation and metamorphism, and of intrusion where this has occurred. The methods can be applied to large areas of ground and provide a sequence which can be linked with age determinations based on the classical methods of stratigraphy, on palaeomagnetic studies, or on measurements made on radioactive minerals. The techniques are complementary and offer the prospect of extending the range of historical geology into regions where the classical methods fail when used alone.

This article has been mainly concerned with the author's work in Scotland, but a similar approach has been used in other countries. Thus for many years a vigorous school of structural geologists in Austria, led by B. Sander, has been studying how the metamorphism and deformation affected the way minerals are arranged in metamorphic rocks. The Norwegian geologist A. Kvale has investigated sequences of events determined in crystalline rocks in Norway which were deformed and metamorphosed during the Caledonian earth movements, and recently he has taken up similar problems in Switzerland in an area where crystalline gneisses that originally developed in an earlier episode of mountain building were deformed once more during the Alpine orogeny. E. Wenk has recently published the results of a prolonged investigation of small-scale structures in the Swiss Alps, and has shown how the study of such features folds a few metres across and the linear arrangement of minerals can be used to work out the historical geology of the crystalline rocks of the Alps.

REFERENCES

[1] HOLMES, A. *Trans. geol. Soc. Glasg.*, **21**, 117, 1947.
[2] MAYNE, K. I., LAMBERT, R. ST J., and YORK, D. *Nature, Lond.*, **183**, 212, 1959.
[3] PEACH, B. N., HORNE, J., GUNN, W., CLOUGH, C. T., HINXMAN, L. W., and TEALL, J. J. H. 'Geological Structure of the N.W. Highlands of Scotland'. *Mem. geol. Surv. Scotl.*, 1907.
[4] SUTTON, J. and WATSON, J. V. *Quart. J. geol. Soc.*, **106**, 241, 1951.
[5] NOE-NYGAARD, A. *Rep.* 18. *Int. geol. Congr., London.* 1948.
[6] WENK, E. *Schweiz. min. petrogr. Mitt.*, **14**, 196, 1934.
[7] HOLMES, A., SHILLIBEER, H. A., and WILSON, J. T. *Nature, Lond.*, **176**, 390, 1955.
[8] GOLDICH, S. S., BAADSGAARD, H., and NIER, O. A. *Trans. Amer. geophys. Un.*, **38**, 547, 1957.
[9] DAVIS, G. L., WETHERILL, G. W., TILTON, G. R., and HOPSON, C. A. *Program Ann. Meeting geol. Soc. Amer.*, 1958.
[10] PEACH, B. N., HORNE, J., WOODWARD, H. B., CLOUGH, C. T., HARKER, A., and WEDD, C. B. 'The Geology of Glenelg, Lochalsh and S.E. part of Skye'. *Mem. geol. Surv. Scotl.*, 1910.
[11] PHILLIPS, F. C. *Quart. J. geol. Soc.*, **93**, 581, 1937.
[12] CRAMPTON, C. B. *Geol. Mag.*, **94**, 89, 1957.
[13] SUTTON, J. and WATSON, J. V. *Quart. J. geol. Soc.*, **108**, 99, 1953.
[14] RAMSAY, J. G. *Ibid.*, **113**, 271, 1958.
[15] WEISS, L. E. *Bull. geol. Soc. Amer.*, **70**, 91, 1959.
[16] RAMSAY, J. G. *Quart. J. geol. Soc.*, **113**, 487, 1958.
[17] SUTTON, J. and WATSON, J. V. *Ibid.*, **114**, 231, 1959.
[18] FLEUTY, M. J. Thesis, University of London. 1956.
[19] READ, H. H. *Trans. roy. Soc. Edinb.*, **59**, 195, 1937.

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Bicentenary of the Royal Botanic Gardens, Kew

C. E. HUBBARD

The Royal Botanic Gardens, Kew, this year celebrate their bicentenary—two hundred years of almost continuous endeavour and advancement. During this time Kew's numerous and varied contributions to botanical science and to the welfare and prosperity of peoples in many lands, particularly those of the British Commonwealth, have gained it international renown.

It was in the year 1759 that the Princess Augusta, Dowager Princess of Wales, founded a botanic garden in the grounds at Kew. As a Royal Garden, however, it dates from 1730, when the Princess's husband Frederick, son of George II, obtained a long lease of Kew House (now demolished) and began laying out about 9 acres of the property. After his death in 1751 the Princess continued to live there and, being keenly interested in all kinds of plants, proceeded with the development of the Garden. In this work she received much help, encouragement, and advice from the Earl of Bute, a great friend of the royal family and an enthusiastic botanist.

There is little information available about the early formation and arrangement of the Garden, although it is known that William Aiton—who had been trained by the celebrated gardener and botanist Philip Miller at the Apothecaries' Garden, Chelsea—was engaged in 1759 to take charge of the laying-out and planting of the new botanic garden at Kew. The area selected for this garden was divided into two nearly equal parts. In the southern half were planted a collection of herbaceous plants arranged according to the Linnean system, a large selection of grasses, and special collections of British and alpine plants. The northern portion, separated from the southern by several hothouses and walls, was planted with trees and shrubs and called the arboretum. Many of these woody plants were recent introductions to Britain, but known to be hardy; a large number of them came in 1762 from the Duke of Argyll's garden at Whitton in Middlesex. Of these there still remain at Kew an ancient maidenhair tree (*Ginkgo biloba*), a false acacia (*Robinia pseudoacacia*), and a Turkey oak (*Quercus cerris*).

Under Bute's guidance, the Garden soon gained recognition as a scientific establishment, and the collections increased rapidly in both quantity and quality. Bute lived at Kew, and kept his botanical specimens and library in a separate building near Princess Augusta's Garden. It was perhaps here that John Hill, a noted botanist of the day, prepared his catalogue, *Hortus Kewensis*, of the 3400 species then cultivated in the Royal Garden —a work of 458 pages, published in 1768. It included 26 new species, mainly of North American origin, 20 of which were illustrated by excellent coloured plates in the second edition, issued in 1769. A manuscript catalogue of the trees and shrubs in the royal collection, prepared in 1773, shows that it then contained 791 species and varieties.

On the death of George II in 1760, Princess Augusta's son succeeded to the throne as George III and took over Richmond House, the residence of his grandfather, the grounds of which were adjacent to those of Kew House. When his mother died in 1772 he purchased the freehold of the latter property, but it was not until 1802 that the two gardens were united. From the joining of the grounds of these two houses the present use of the plural title, Royal Botanic Gardens, has been derived.

In 1771 or 1772 the young king became acquainted with Mr (later Sir) Joseph Banks, who had just returned from Captain Cook's voyage of discovery to the Pacific Ocean in the *Endeavour*, during which he had served as naturalist. He became the King's scientific adviser and, taking a keen interest in Kew, succeeded Bute as honorary director of the establishment. Under his guidance the Gardens soon became the principal European botanical institution devoted to the culture of plants, being famed for the great diversity and scientific value of their collections. Scarcely a voyage of discovery of any importance left the shores of Britain without one of Banks's botanists or plant-collectors from Kew, and he sent others on

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special expeditions to many parts of the world to gather seeds and plants to add to the ever-increasing catalogue of Kew plants.

Three examples from the early records of Banks's introduction of plants may be mentioned here, but many other collectors gave similar valuable help in the interchange of economic and horticulturally important plants carried out at Kew, a service in which it is still actively engaged.

The first of Banks's plant-collectors, Francis Masson, a gardener at Kew, was sent to the Cape of Good Hope at the beginning of 1772, where during two and a half years he gathered a great profusion of new plants for the Royal Gardens; on some of his expeditions he was accompanied by Thunberg, a famous pupil of Linnaeus. He also visited the Canary and other North Atlantic islands as well as the West Indies before returning once again to the Cape for almost ten years. In paying tribute to Masson, Banks stated it was in great measure as a result of his endeavours that Kew attained its acknowledged superiority over similar establishments.

Another famous enterprise in which Banks and Kew were closely concerned was Captain William Bligh's voyage in the *Bounty* in 1787 to the South Seas to collect plants of the breadfruit for introduction to the West Indies. Bligh was accompanied by two Kew gardeners, David Nelson and William Brown. Although the expedition obtained large numbers of plants, the mutiny of the crew, in which Brown joined, led to the failure of the project. On a similar mission in the *Providence* in 1791, Bligh—accompanied once more by two Kew men, Christopher Smith and J. Wiles—was successful in safely conveying a cargo of young breadfruit trees to Jamaica and other West Indian islands, whence they were rapidly introduced throughout the region. Another economically valuable plant, the Otaheite sugar-cane, was introduced by Bligh's collectors at the same time. By 1819 this cane had become firmly established throughout the West Indies, and it is recorded that on Barbados the annual yield of sugar from it for the preceding five years averaged 12 565 tons. For at least a century this variety of sugar-cane was planted almost to the exclusion of any other in Barbados, but finally it became weakened by disease and its cultivation had to be abandoned.

Masson was the first of a long line of Kew men who during Banks's lifetime, and after his death in 1820, dispatched vast numbers of plants and seeds to the Gardens. James Bowie and Allan Cunningham were sent to Brazil in 1814, George Caley travelled to Australia in 1799, and William Kerr to China in 1803. In 1817 Cunningham was posted to New South Wales. As a result of his journeys there and in other parts of Australia he became internationally famous as a botanist and explorer. A continuous stream of new and rare plants, living and dried, was sent home by this remarkable young man. He travelled widely, far into the interior of New South Wales, crossed the Great Dividing Range in Queensland through the gap which now bears his name, and accompanied Captain King in the *Mermaid* on the surveys of the north and north-west coasts of Australia.

The names of some of the plant introductions of the Kew botanical collectors were incorporated in the *Hortus Kewensis* of William Aiton, published in 1789, in which about 5500 species are described. Others are listed in the second edition of this work by his son, who succeeded him as a superintendent of the Gardens in 1793. By then, 1810–13, the number of species grown had increased to 9800.

During the twenty-one years following Banks's death the Gardens suffered from a certain amount of neglect in their management, although the plants were maintained in a good state of cultivation by the gardening staff, especially as a result of the industry and enthusiasm of John Smith, who became Curator in 1841. The unsatisfactory condition of the Gardens was brought to the notice of the Government and led to the appointment in 1838 of a committee of inquiry consisting of a botanist, John Lindley, and two gardeners, Mr (later Sir) Joseph Paxton and Mr Wilson. As a result of their recommendations the control of the Gardens was transferred to the Commissioners of Woods and Forests in 1840. Dr (later Sir) William Jackson Hooker, Professor of Botany in the University of Glasgow, was nominated their first official Director in April 1841.

There were then about 15 acres of grounds, crowded with trees, shrubs, and herbaceous plants, but there was no herbarium, museum, or laboratory. The greenhouses were in a bad state of repair, and both these and the Gardens generally were totally inadequate for the rich collections already there, quite apart from the plants and seeds which constantly arrived from every quarter of the globe. However, before Hooker's death in 1865, not only had the huge Palm and Temperate houses and the first Museum of Economic Botany been built and a magnificent herbarium and library established in Hunter House, but the layout of the grounds had been reorganized, and they were extended nearly to their

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present size and judiciously planted with a fine selection of hardy trees, shrubs, and herbs.

Hooker edited various scientific periodicals, such as the 'Botanical Magazine', the *Icones Plantarum*, and his own 'Journal of Botany', to all of which he contributed numerous articles; the first two continue to be prepared at Kew almost 120 years later. It was he who planned and initiated the extensive series of floras of the countries of what is now the British Commonwealth, in the elaboration of which Kew continues to provide botanists everywhere with taxonomic works for the identification of plants. In these and many other ways he laid the foundation for the future development of Kew as an international centre for botanical research. He attracted and encouraged botanists of all nations by a very extensive correspondence, by the provision of excellent facilities for study, by the exchange of living and preserved plant-material, and by organizing surveying and collecting expeditions to undeveloped regions.

Under the wise direction of Dr (later Sir) Joseph Dalton Hooker, who succeeded his father in 1865, the Gardens continued to prosper, improvements and additions being made to all parts of them. He collaborated with his friend, George Bentham, in the preparation of the *Genera Plantarum*, a descriptive account in Latin of all the genera of Phanerogams and Gymnosperms. This is a classical work on their taxonomy, and it has provided an excellent basis for the arrangement of many floras and plant-lists, both for the botanical collections at Kew and for other Commonwealth and foreign herbaria. His own contributions to botany, especially in the fields of description, classification, and phytogeography, were enormous. He edited and wrote much of the 'Flora of British India', besides floras of New Zealand, Tasmania, and the Antarctic regions. The Jodrell Laboratory for research in anatomy and physiology was built in 1876, and a new wing was added to the Herbarium in 1877 to house the huge collections of dried specimens received at Kew. Before Sir Joseph Hooker retired in 1885, Kew had become the foremost international centre for botanical research, particularly in systematic botany.

The Royal Botanic Gardens, Kew, as we know them today, are very largely the creation of the two Hookers, both endowed with tremendous energy, remarkable foresight, and ability. They were first-class administrators and organizers and, above all, botanists of the highest quality. Subsequent Directors continued the policy of their distinguished predecessors in fostering a close association with botanists and botanical establishments in the countries of the British Commonwealth, especially in matters concerning taxonomic and economic botany. The 'Kew Bulletin' began publication in 1887 to record the results of researches carried out at Kew; with its additional series and supplements this now comprises eighty volumes.

The main functions of the Gardens, as envisaged about the time of their presentation to the nation by Queen Victoria in 1841, were scientific work; the cultivation of plants from all parts of the world; the instruction of the public; the propagation of useful plants for distribution to various overseas territories of the British Commonwealth; and, finally, furnishing the Government with general information on botanical subjects. At the present day, with these purposes in mind, the Gardens are divided into the following five departments:

1. Herbarium and Library, a research institution primarily for the accurate identification and classification of plants.
2. Jodrell Laboratory, a research department for the study of the anatomy and physiology of plants.
3. Museums of Economic Botany, for the instruction of the public in the uses of plants, the supply of information in the field of applied botany, and the economic exploitation of plants.
4. The living collections in the Gardens, in which are cultivated more than 25 000 species of flowering plants and ferns and from which plants and seeds are distributed to similar establishments both at home and overseas.
5. The National Pinetum, Bedgebury, Kent, containing the living collection of hardy species of the *Coniferae*.

The Herbarium and Library were founded in 1853, when accommodation for specimens and books was provided in Hunter (Hanover) House, previously the residence of the Duchess of Cumberland and her husband. The collections forming the basis of this department were those of William Arnold Bromfield; the extremely valuable herbarium and library of George Bentham, given in 1854; and the huge collections of Sir William Hooker which had been on loan to Kew since 1841 and were purchased in 1866. The joint herbaria of Bentham and Hooker, together with other important gifts and purchases of botanical collections,

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provided the establishment with an excellent foundation for the floristic researches planned by Sir William.

KEW TODAY

The Herbarium continues to increase as the vegetation of all regions is studied in greater detail, the additions over the past ten years averaging about 60 000 annually. The specimens are housed in three wings, the total collection comprising over six and a half million sheets of mounted material of all groups of plants; it includes a fairly high representation of the known species from most parts of the world. The dried material is supplemented by more than 15 000 bottles of flowers and fruits in liquid preservative and by large numbers of fruits and seeds in boxes. The Herbarium is exceptionally rich in original (type) and authentically named specimens. Because of these, and of the historic material which formed the basis of the earlier Kew floras, the assistance of Kew is continually being sought by botanists overseas in the revision of existing works and in the writing of new floras.

The results of research carried out in the Herbarium by members of the staff and by visiting workers, many of whom have spent long periods at Kew, have been published as papers in a wide range of scientific periodicals or as separate works. In 1863, Sir William Hooker put forward his proposals for a series of floras of parts of the British Commonwealth, and the preparation of these has claimed the attention of Kew botanists and visiting workers for about a hundred years. Starting with the Flora of the British West Indian Islands between 1859 and 1864, the series has included accounts of the plants of Australia, Tasmania, New Zealand, the Fiji Islands, the Malay Peninsula, Hong Kong, India and Ceylon, Mauritius and the Seychelles, tropical Africa, South Africa, and of smaller regions and islands, mainly in the Old World. Floras now in preparation in the Herbarium include the second edition of the 'Flora of West Tropical Africa', a 'Flora of Tropical East Africa', and floras of Cyprus and of Iraq.

The abstracting of new generic and specific names of flowering plants from botanical literature, for listing with their place of publication and country of origin in the *Index Kewensis* is still being carried out. This indispensable service for botanists, horticulturists, and others working with plants was commenced at the suggestion of, and financed in the first place by, Charles Darwin. It comprises 14 large quarto volumes. A supplement is issued now for each period of five years; that for the quinquennium 1951–55 contained about 20 500 names. The original two volumes were published in 1895 and the 12 supplements include about 830 000 entries of generic and specific names.

The *Index Londinensis*, listing the published illustrations of flowering plants and ferns, the compilation of which was undertaken at Kew and financed by the Royal Horticultural Society, consists of four volumes and two supplements, the whole covering the years 1753–1935. This important work is not only of great value as an index to plant portraits but also as a guide to the literature on a particular plant, as many such studies include an illustration.

Botanical art is not neglected at Kew. Since 1841 the 'Botanical Magazine' has been edited and mainly prepared there, its illustrations in colour of individual plants now totalling about 10 000 plates and filling 172 volumes. The 36 volumes of the *Icones Plantarum* contain nearly 3600 illustrations in black and white and descriptions of new or rare plants in the Herbarium.

The Library is thought to be the largest and the most comprehensive collection of botanical works in existence. It comprises over 55 000 bound volumes, about 80 000 separates and reprints, a collection of about 150 000 paintings, drawings, and photographs, and approximately 6500 maps. The number of periodicals taken is 700.

The Jodrell Laboratory, which was built and equipped in 1876 at the expense of T. J. Phillips Jodrell to provide facilities for research in plant anatomy and plant physiology, is still a comparatively small building. Nevertheless, many famous botanists have carried out fundamental anatomical, biochemical, mycological, and physiological investigations within its walls. The microscopical identification of timbers, fibres, and parts of plants used for medicinal and other purposes has been one of its chief services to scientific botany. In this connection the present Keeper of the Laboratory, Dr C. R. Metcalfe, collaborated with L. Chalk in the preparation of a new work of 1500 pages on the 'Anatomy of the Dicotyledons', published in 1950. It is based on a review of the literature on this subject published since the appearance of Solereder's 'Systematic Anatomy of the Dicotyledons' in 1908, and on the results of original observations made on a vast collection of microscopic preparations of the tissues of stems, leaves, and roots, commenced in 1930 and now numbering more than 20 000 slides. The staff,

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with the assistance of collaborators in other institutions, is now engaged on the preparation of a companion study of the anatomy of the Monocotyledons, of which the first volume, relating to the grasses, is now being printed. The Laboratory provides a unique centre for investigation of botanical problems requiring the co-operation of taxonomists, anatomists, cytologists, and physiologists, since in no other institution in the world is such a wealth of plant material available for study.

The three Museums of Economic Botany contain vast collections of plant products of all kinds used in identification, for research, and for display purposes. Two are devoted to the Dicotyledons and Monocotyledons, and one to the collection of timbers and objects made of wood. The staff of this department, being concerned mainly with the economic exploitation of plants, has to answer a wide range of inquiries relating to their uses, and in so doing has investigated in recent years vegetable gums and resins, tanning materials, fibres, medicinal plants, and nuts and seeds in great variety.

Kew has played a most important part in the introduction of new plants of economic value to many countries of the Commonwealth, two well-known examples being the supply of Para Rubber to Malaya and Ceylon and of species of *Cinchona* (the source of quinine) to India. Kew has sent out a great variety of useful plants since its early days. At first a wide range of fruits, nuts, vegetables, and ornamental plants were sent to newly developed areas for the use of the settlers and, later, a variety of other economic plants such as forest trees, medicinal plants, and others yielding fibres, resins, gums, and oils, as well as cereals and crop plants of many kinds. Kew continues to serve as a quarantine station where plants in transit from one part of the Commonwealth to another may be inspected and held for some time to prevent the spread of diseases and pests. For example, those of cacao, banana, cotton, and rubber have passed through Kew before transmission to Ghana, Nigeria, Malaya, Fiji, Trinidad, and Ceylon. An active exchange of living plants and seeds has been maintained since Banks's time with botanical, horticultural, and agricultural institutions both at home and overseas. Many of the ornamental plants of North and South America, eastern Asia, Australia, New Zealand, and South Africa have been propagated at Kew and distributed through European and American botanical establishments to enrich private gardens in many lands.

In addition to its other services the Royal Botanic Gardens have from the first provided excellent opportunities for those seeking to improve their knowledge of botany and horticulture. Many members of its junior staff, benefiting from the extensive practical and theoretical training received in the Gardens, have gone to all parts of the Commonwealth as curators of botanic gardens and agricultural experiment stations, or have taken charge of plantations, nurseries, parks, and gardens. At the present time Kew-trained men occupy important posts in 54 countries. The largest number overseas are in the United States; but many are to be found in Canada, New Zealand, South Africa, and Australia. From time to time gardeners from Kew have travelled widely in the Himalayas, western China, and North and South America, and in so doing have made valuable collections of seeds for the Gardens and of dried specimens for the Herbarium.

From the time of Sir William Hooker, Kew botanists have been sent on expeditions and missions of investigation and exploration or have joined surveying parties, to study the vegetation of the regions concerned and to preserve plants for the Herbarium. Since 1920 extensive collections have been made in this way in British Guiana, West Indies, Ceylon, Indonesia, Australia, and most Commonwealth countries in Africa.

In this age of specialization it is no longer possible for those studying plant life to cover the entire field of pure and applied botany, except in a very general manner. Thus Kew's investigations are concerned mainly with the taxonomy and anatomy of plants and their cultivation and economic uses. They might be extended with advantage, however, to include most branches of plant science, and so make the fullest use of the unrivalled collections.

BIBLIOGRAPHY

BEAN, W. J. 'The Royal Botanic Gardens, Kew'. London. 1908.

BOULGER, G. S. *S. East. Nat.*, **20**, 61, 1915.

HILL, A. W. *J.R. Soc. Arts*, **72**, 87, 1923.

SALISBURY, E. J. *Ibid.*, **94**, 336, 1946.

Idem. Endeavour, **6**, 58, 1947.

Idem. Proc. roy. Soc., B, **135**, 419, 1948.

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Book reviews

PHILOSOPHY AND ASTRONOMY

The Individual and the Universe, *by A. C. B. Lovell. Pp. v+111. Oxford University Press, London.* 1959. 10*s.* 6*d. net.*

The technical developments in radio astronomy and the launching of earth satellites have within recent years brought about a revolution in astronomical observations. The large radio telescopes of today can probe the universe to depths beyond those accessible to the Palomar 200 in. telescope. These developments may have suggested to Professor Lovell 'The Individual and the Universe' as the subject of the Reith Lectures broadcast by him in 1958 and published in this book.

In the course of the lectures the progressive change in man's outlook on the universe is outlined, from the view, which prevailed for many centuries, that the Earth was the centre of the universe to the present view. The possibility is discussed of a decisive observational test between the two rival cosmologies, the one supposing that there was an initial creation of a primeval atom, and the other assuming that the universe is in a steady state, with the necessary consequence of the continuous creation of matter.

Large radio telescopes are expensive to build and operate. This raises the question of state support for astronomy, which is discussed at some length. Such support was given in the United Kingdom long before it was given in the United States, but the great advance in observational astronomy in the United States in fact followed the many private benefactions for the construction of large telescopes. The rapid developments in astronomy in the Soviet Union, on the other hand, have been brought about by the considerable funds provided by the Academy of Sciences, a state organization.

Various developments in astronomy are now linked with the requirements of the armed services. The basis of the present economic and cultural strength of the Great Powers can be traced back, as Professor Lovell points out, to fundamental scientific investigations carried out in the abstract, without thought of direct practical developments. But now, in astronomy as in some other branches of science, the pursuit of good and evil are linked. This is a situation that cannot be regarded without some apprehension for the future; restraints on freedom of investigation and publication may reduce the effectiveness of research.

H. SPENCER JONES

QUANTUM MECHANICS

Quantum Mechanics. Non-Relativistic Theory, *by L. D. Landau and E. M. Lifshitz (translated from the Russian by J. B. Sykes and J. S. Bell). Pp. xii+515. Pergamon Press Ltd, London.* 1958. 80*s. net.*

This is volume III of the authors' course in theoretical physics. The contents comprise non-relativistic quantum mechanics and some of its applications. More particularly, the topics discussed include basic principles, motion in a central field, perturbation theory, electron spin, theory of atoms, di- and polyatomic molecules, theory of symmetry, and theory of elastic and inelastic collisions. In the authors' words, 'We have tried to deal as fully as possible with those topics that are included—we attempt to discuss general topics in such a way that the physical significance of the theory is exhibited as clearly as possible and then to build up the mathematical formalism. In doing so we do not aim at mathematical rigour of exposition which in theoretical physics often amounts to self-deception.'

I consider this as perhaps the best textbook available on non-relativistic quantum theory. The comparison is of course not with the works of Dirac and Pauli. The present volume attempts to teach more by example than precept. There seems, at present, a phase in textbook writing in the Soviet Union (at least among most texts so far translated) which combines comprehensiveness as well as depth with admirable readability. There is a sense of artistic delight in detail, and this book is fully a part of this growing tradition. Someone has discovered the happy secret which persuades the best men in science to write textbooks.

A. SALAM

ELEMENTARY PARTICLES

Progress in Elementary Particle and Cosmic Ray Physics, *Vol. IV, edited by J. G. Wilson and S. A. Wouthuysen. Pp. xii+470. North-Holland Publishing Co., Amsterdam.* 1958. 45 *guilders.*

This is the fourth volume in the well-known North-Holland series on elementary particles and cosmic rays. The earlier volumes of the series confined themselves to elementary particle interactions as observed in cosmic rays. With the present volume a departure has been made to include also data from the great accelerating machines in the United States. This change of emphasis reflects itself in a chapter on κ-meson production (W. D. Walker) and a chapter on theoretical ideas concerning the phenomena of 'strange' particles (B. D'Espagnat and J. Prentki). The remaining three chapters, forming the bulk of the book, deal with interaction of μ-mesons with matter (G. N. Fowler and A. W. Wolfendale), the composition and time variation of primary cosmic radiation (S. F. Singer) and the origin of cosmic radiation (V. L. Ginzburg). The difference in treatment between the first two and the remaining chapters is perhaps characteristic of the preliminary—and in the case of theoretical ideas mainly speculative—nature of the work in elementary particle physics as contrasted with the stage of 'maturity' reached in cosmic-ray physics. If only for the sake of the last three chapters, the book is invaluable for the workers in this field.

A. SALAM

NUCLEAR PHYSICS

Nuclear Structure, *by L. Eisenbud and E. P. Wigner. Pp. viii+128. Princeton University Press, Princeton; Oxford University Press, London.* 1958. 25*s. net.*

In the post-war years a great deal of effort in both experimental and theoretical physics has been devoted to the study of the atomic nucleus. Although we still do not know the detailed form of the interaction between nucleons, considerable progress has been made in interpreting the wide range of experimental data concerning complex nuclei. This is still largely carried out in terms of simple models such as the shell model or the alpha-particle model. None of these can represent more than a certain number of observed facts about nuclei, but the success of some of them, particularly the shell model, has been greater than expected. Nuclear physics is still in the Keplerian phase where order is being sought amid the great wealth of experimental data. The Newtonian phase will have commenced when we fully understand why some of the models are so successful.

The great merit of this book is its conciseness. At no time is the reader lost in a mass of detail, and yet sufficient data are given to explain the need for

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the introduction of a particular interpretative mode of approach and to discuss its successes and limitations. The authors are to be congratulated on this excellent contribution to the understanding of the subject. This book will not only be of the greatest value to students beginning serious study of nuclear physics, but will be of absorbing interest to experienced workers in the field who have not had the opportunity of sitting back and calmly reviewing the situation reached. The fact that a book of this kind can be written at all is strong evidence that a considerable degree of order already prevails.

The first four chapters are concerned with summarizing nuclear properties, being on, respectively, general features of nuclei, systematics of stable nuclei, properties of nuclear states, and survey of nuclear reactions. After a brief account of the interaction between nucleons in chapter 5, the next three chapters are concerned with nuclear models—the uniform model in chapter 6, independent particle models in chapter 7, and many-particle models in chapter 8. Chapters 9 and 10 deal with nuclear reactions, the former being concerned with close collisions and the latter with surface reaction. The final two chapters discuss interaction with electron-neutrino fields and electromagnetic transitions in nuclei. A very useful list of references occupies the last ten pages. H. S. W. MASSEY

CHEMICAL KINETICS

Some Problems of Chemical Kinetics and Reactivity, *Vol. I, by N. N. Semenov. Translated from the Russian by J. E. S. Bradley. Pp. x+305. Pergamon Press Ltd, London.* 1958. 50*s. net.*

Academician Semenov is world famous for his contributions to the theory of chain reactions. The subject itself has spread over the world by a branching chain, and there is a vast amount of experimental data on chemical systems of the most diverse kinds. In this book the author seeks in some measure to systematize this great accumulation.

He tabulates activation energies, heats of reaction, bond energies, relative reactivities of different radicals, and so on, and wherever possible relates them, sometimes by expressions of a semi-empirical quantitative nature.

Free radical reactions are classified, and methods of finding the constants of individual steps are discussed. Where possible, the principles which allow the absolute rate of each step to be predicted in order of magnitude are considered.

Methods of initiation and termination are analysed in great detail, heterogeneous initiation of chains by free valency sites on walls of containing vessels being discussed in an interesting and suggestive way. There is a description of some recent Russian work which, if not wholly convincing, is ingenious and thought-provoking.

The book is written by a master hand. It makes clear the personal view of its distinguished author on the major disputed topics (and sometimes this view does not altogether commend itself to the reviewer): it always provides a wide survey of the literature, and on controversial matters both sides of the question are usually well stated. C. N. HINSHELWOOD

INORGANIC CHEMISTRY

Nouveau traité de chimie minérale, *Vols. III and IV, edited by P. Pascal. Vol. III, pp. xii+838. Vol. IV, pp. xxxix+973. Masson et Cie., Paris.* 1957 and 1958. *Vol. III, paper covers, fcs.* 6000; *bound, fcs.* 6900 *net. Vol. IV, paper covers, fcs.* 7500; *bound, fcs.* 8500.

This new treatise on inorganic chemistry when completed will consist of twenty volumes. The third and fourth volumes have recently appeared and constitute a valuable part of the new work. The third volume is concerned with the elements rubidium, caesium, francium, copper, silver, and gold, while the fourth volume is devoted to an account of the sub-group beryllium, magnesium, calcium, strontium, barium, and radium. The various authors follow a general pattern in the treatment of this subject. A short history of the element, and an account of its occurrence in nature and its isolation, are given concisely, and then follows a detailed account of its more important physical and chemical properties. Mention is made of the analytical chemistry of the element, with a section on its main uses. Finally, a wealth of information is given about interesting and important compounds which the element forms with a wide range of other elements. Some idea of the comprehensive nature of the information included can be seen from the fact that in the third volume, 6997 references are given to original papers relevant to items mentioned in the text. In the fourth volume the number of references is 8873. When an element forms derivatives involving the use of organic substances, such organometallic compounds are specially dealt with. It is appropriate that the account of the element francium should be written by Marguerite Perey. The literature is full of early claims and counterclaims to the isolation of element 87, but until the work of Marguerite Perey in 1946 none of the claims were substantiated to the general satisfaction of critical reviewers. The name agreed by the International Union of Chemistry is francium and the symbol Fr. Incidentally, the references to this element do not go beyond 1st April 1956. The various authors who contribute to these two volumes are to be congratulated on an exposition orderly, lucid, and detailed, and the publishers must be complimented on the production of two very handsome volumes. One cannot but regret that the cost of the whole work will place it beyond the means of many libraries and institutions where it might be most useful. W. WARDLAW

ROCKETS AND SATELLITES

Rockets and Satellites, *edited by L. V. Berkner. Pp. xx+508. Pergamon Press Ltd, London.* 1958. £8 *net.*

Before the International Geophysical Year more than 100 rockets were launched into the upper atmosphere in the conduct of scientific research. The I.G.Y. was distinguished from earlier international co-operations in many ways, not the least being the extensive use of these new techniques—indeed, it will always be remembered most of all for the introduction and phenomenally rapid development of the use of artificial satellites. There is no single source to which an inquirer may turn in his search for data on these aspects of research, but in this book, which is Volume IV of the Annals of the I.G.Y., there is a miscellaneous collection of information on the research programmes, instrumentation, and vehicles of many nations. A very large part is taken up with descriptions of the huge research effort of the United States. It is a pity that the comparable effort of the Soviet Union has not been reported in detail. This, however, is not the fault of the editor. Presentation is far from uniform, for the book is simply a compilation, and it is sometimes repetitive. Nevertheless it remains a valuable and in many ways a comprehensive work of reference. R. L. F. BOYD

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THE UPPER ATMOSPHERE

The Upper Atmosphere, *by H. S. W. Massey and R. L. F. Boyd. Pp. xii+333. Hutchinson & Co. Ltd, London.* 1958. 63*s. net.*

This book compresses into a little over 300 pages a readable and accurate account of our present knowledge of the phenomena taking place in the upper atmosphere, that is, at heights above about 30 miles. It begins with an account of 'The Relevant Physics' for the benefit of the non-scientist and, after a short general chapter on 'The Atmosphere', describes the techniques employing balloons and rockets for exploring the upper air. The next chapter describes the methods of measuring the temperature of the upper air by reflected sound waves and the ionization of the upper air by reflected radio waves, while chapters 6 and 8 describe the variations of the Earth's magnetic field and of the ionosphere under 'quiet' conditions. Chapter 9 gives an account of the disturbances which may occur on the Sun and the effects of these on the subjects of chapters 6 and 8. Chapter 7 brings together accounts of the luminous phenomena in the atmosphere, the air glow, the closely associated twilight flash, the aurora, and artificial glows produced by the injection of either sodium vapour or nitric oxide into the upper atmosphere. The book ends with a very good discussion of meteors, cosmic rays, and artificial satellites. Both the general and the scientific reader will find this an interesting and accurate account of the subject.

G. M. M. DOBSON

METEOROLOGY

The Green Flash and Other Low Sun Phenomena (*second edition*), *by D. J. K. O'Connell. Pp.* 192. *North-Holland Publishing Co., Amsterdam; Interscience Publishers Inc., New York.* 1958. 45*s. net.*

In this book on sunrise and sunset optical effects, pride of place is given to the green flash, perhaps the most striking of all atmospheric optical phenomena. Historical observations and hypotheses are described and a remarkably large bibliography on the effect is included.

There has been for some forty years no reasonable doubt that the green flash is a real physical effect which is to be explained in terms of differential wavelength refraction and absorption of the sun's light. The chief remaining doubt is the precise meteorological conditions which favour the appearance of the effect. Its notorious capriciousness suggests the need for atmospheric super-refraction (as when an air stream is cooled from below); the suggestion is strongly supported by the radiosonde temperature data quoted in the book but it is not supported to a significant degree by the measure of refraction afforded by a comparison of actual and theoretical sunset times on occasions of the green flash. It is rather disappointing that there is only scanty discussion of this aspect of the phenomenon.

The book is chiefly remarkable for its excellent photographs (colour, and black and white) of the green flash and other effects, taken at the Vatican Observatory by means of a telescope fitted with a camera.

D. H. McINTOSH

ETHNOLOGY

Ciba Foundation Symposium on Medical Biology and Etruscan Origins, *edited by G. E. W. Wolstenholme and C. M. O'Connor. Pp. xii+255. J. & A. Churchill Ltd, London.* 1959. 45*s. net.*

This novel symposium, conceived by a biochemist and a classicist respectively of the University of Cambridge, was effectively summoned into existence by the Director of the Ciba Foundation, who brought together geneticists and physical anthropologists on the one hand, and archaeologists and historians on the other, and suggested that the biologists should help the humanists to settle, if possible, the long-disputed problem of the origin of the Etruscans. It is easy to collect conflicting statements about almost everything Etruscan, and in regard to central Italy we have not enough reliable data to allow us to draw either positive or negative conclusions about the existence of differences in blood group distribution which could eventually be related to the ethnic influence of the Etruscans. But the book is replete with interest, and should appeal to many in different disciplines. The members of the Symposium, aware of the value of studies on the frequency of distribution of blood groups for the understanding of important—and so far insufficiently investigated—points in common between the different ethnic groups, addressed a resolution to the National Committee for the Study of Blood Groups in Italy. Congratulations should rightly go to the Director for the successful establishment of a new technique.

K. J. FRANKLIN

YEASTS

The Chemistry and Biology of Yeasts, *edited by A. H. Cook. Pp. xii+763. Academic Press Inc., New York; Academic Books Ltd, London.* 1958. $22.

A definite need existed for a book on the chemistry and biology of yeasts, and this volume will be welcomed eagerly by all interested in the subject. To encompass the ever-expanding universe of our recorded knowledge on yeast within the covers of one volume has been no light task, and the authors and editor deserve much credit for the manner in which this has been accomplished.

In this book will be found much well presented information on yeasts that has not been assembled elsewhere. The information does not always appear where it might be expected, and the index reveals that only two of the references to respiration are given in the chapter entitled 'Fermentation and Respiration'. On the other hand, careful editing has obviously prevented much overlapping of subject matter in different chapters. Unfortunately, in a book where the various chapters have been entrusted to different authors it is difficult to present the yeast cell as one co-ordinated system and to portray the various frontiers of our advancing knowledge as a connected whole.

The book is well produced and can be strongly recommended. It should be read by all concerned with yeast, and many will want to keep it close at hand.

A. K. MILLS

ZOOLOGY

Anatomie de *Latimeria chalumnae. Vol. I,* Squelette et muscles, *by J. Millot and J. Anthony. Pp.* 122. *Centre National de la Recherche Scientifique, Paris.* 1958. *Fcs.* 9800.

In this sumptuous volume are summarized the results of Professor Millot's and Dr Anthony's careful investigations over a period of five years on the skeleton and muscles of *Latimeria* (coelacanth). The first volume of their fully detailed descriptions of the internal anatomy of these astonishing fishes has been devoted to the skeleton and musculature in view of the major importance in palaeontology of skeletal structures and the possibilities they offer of fruitful comparisons with extinct forms. Palaeontologists will indeed be grateful for this consideration, and they would scarcely be human if their gratitude were not tinged with a little envy at the

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opportunities afforded by this marvellous material. Ten specimens of *Latimeria* in good condition, seven males and three females, have been available to the authors.

The outstanding results have already been announced in papers by Professor Millot and his colleagues, but here are the details so necessary for the palaeontologist to compare the living fish with his all too fragmentary material. The authors make valuable comparisons with the extinct forms and provide some salutary lessons in regard to the interpretation of fossil material—as, for example, in the lack of correlation between the enormous cranial cavity and the diminutive brain. E. I. WHITE

PROTECTION FROM RADIATION

Radiation Protection, *by C. B. Braestrup and H. O. Wyckoff. Pp. xix+361. Charles C. Thomas, Springfield, U.S.A.; Blackwell Scientific Publications, Oxford.* 1958. 80*s. net.*

This book presents a balanced picture of the hazards of radiation, but most of the protective measures discussed are in the medical field. This emphasis should be borne in mind by those seeking a guide to the more general aspects of protection.

Fluoroscopy comes in for some much-needed criticism as one of the most dangerous techniques, on account of the large total doses which may be given to both patient and operator.

Most of the discussion on shielding relates to the structure of buildings and, while this is important, there could well have been more attention paid to recent developments in X-ray machines directed towards restricting the radiation to the useful beam. The references are generally well chosen, but since they date up to the middle of 1958 they might have included the above topic. The protection of specific organs in the patient by individual shields is covered rather briefly.

In the section on luminizing operations, polonium is grouped with radium as a gamma-ray emitter. This is misleading, because polonium emits one gamma-ray to about every hundred thousand alpha-particles and so is considered to be a pure alpha-emitter for most practical purposes.

The book is well written and can be recommended as a guide to the subject, especially for radiographers. The last appendix, on cases of real and imaginary radiation injury, leaves the reader firmly on his feet. S. JEFFERSON

NUCLEAR EXPLOSIONS

Nuclear Explosions and their Effects *(revised and enlarged), foreword by Jawaharlal Nehru. Pp.* 276. *The Publications Division, Ministry of Information and Broadcasting, Government of India, Delhi.* 1958. 25*s. net.*

Essentially this book is an appreciation of biological hazards. The first four chapters, covering some 60 pages, outline the history, physical principles, and general effects of nuclear weapons. The next three chapters, on the biological effects, occupy over 200 pages.

The first edition appeared in 1956 and was a useful supplement to reports of the Medical Research Council (U.K.) and Academy of Sciences (U.S.A.) on biological hazards from all forms of ionizing radiation, whether produced for military or civil purposes.

This, the second edition, 'in its discussion of the hazards of nuclear explosions . . . goes very much further than the first edition, but the broad conclusions remain substantially the same', according to D. S. Kothari in an editor's preface. It appears at the same time as the recent report of the United Nations Scientific Committee on the Effects of Atomic Radiation and of necessity must be compared with this.

There can be no doubt that in war nuclear weapons could have horrifyingly lethal, dynamic, thermal, and radiological effects. What is contentious is the quantitative biological effect from the testing of such weapons in peacetime. The U.N.O. Committee accepted that there would be genetic consequences but rated them small compared with those of medical radiology: it treated potential damage to the individual (somatic effect) in two ways, the more pessimistic fundamentally comparable with the genetic and without a threshold, the more optimistic with a threshold which could scarcely be exceeded except in war or accident. Its report therefore gives the impression of being judicial. The Indian authors of this work give extreme weight to the theory that delayed somatic effects have no threshold for radiation dose and are uncorrelated with dose-rate. For example, page 199, 'the trend of present evidence favours the view that leukaemia is caused by mutations in (somatic) cells in the blood forming organs'—a statement which the reviewer and most investigators in the cancer field will strongly contest. Thus one is left with the feeling that the book advocates one point of view. J. F. LOUTIT

HAEMATOLOGY

British Medical Bulletin, *Vol. XV, No. I.* Symposium on Haematology. *Pp.* 88. *The British Council, London.* 1959. 20*s. net.*

It is a fortunate coincidence that in this year 1959, when the European Society of Haematology is to meet in London, the first number of the British Medical Bulletin should be devoted to haematology. The first three papers deal with the absorption of iron and vitamin B_{12} and the role of folic acid in anaemia. With both iron and vitamin B_{12} the advance made possible by radioactive isotopes has now been consolidated, but although much is known about the part played by folic acid in biochemical reactions, methods for determining the folic acid status of the intact organism are still unsatisfactory. A second group of papers deals with haemoglobin. Many different varieties of haemoglobin have been discovered in the last decade. New light has been thrown on the balance between genetic and environmental factors in human populations, and the chemical nature of the defect in haemoglobin produced by the mutant gene has been determined. Other papers are concerned with haemolysis and the haemolytic anaemias—where the nicest bit of tidying up in clinical haematology since the war has taken place—the cytology of the blood cells and leukaemia. The high standard of editing of the articles deserves a special mention. L. J. WITTS

WAVEGUIDES

Proceedings of the Symposium on Electronic Waveguides, New York, April 1958, *edited by J. Fox. Pp. xix+418. Interscience Publishers Inc, New York; Interscience Publishers Ltd, London.* 1958. 40*s. net.*

The title of this symposium is an intriguing one in that, although the subjects of electronics and of waveguides are now both widely studied, they are not normally associated. The implications are, however, made clear in the foreword by Dr Weber, the President of Brooklyn Polytechnic, where the symposium was held. There are now many situations in which electromagnetic waves and electron beams interact, examples being the many varieties of microwave amplifiers and oscillators, and the propagation of radio waves in the ionosphere. The theoretical background of such diverse

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problems stems from Maxwell's equations and the electrodynamical equations. In this volume twenty-six papers by the leading workers in this field have been collected and provide a very useful summary of the present state of development of this very important subject. The emphasis throughout is on basic principles, and although particular microwave devices are discussed, they are brought in primarily to illustrate the principles.

The book will be of most immediate value to those concerned with the design of microwave valves, and such readers will appreciate the speed with which the book has been published. A number of the articles have a more general interest, and that by Dr Kompfner on the new amplifiers and oscillators based on solid-state quantum effects and on the use of variable-reactance elements provides a masterly introduction to this subject. The general theorems on the interaction between electromagnetic waves and electron beams will undoubtedly also find applications in the field of magnetohydrodynamics, which is now of great importance in the current work on fusion.

J. BROWN

PLANT PATHOLOGY

Le Malattie delle Piante. *Part I*, Malattie da virus e da parassiti vegetali, *by J. Ceruti Scurti. Pp. viii+390. Loescher, Turin.* 1958. *Lire* 2500.

The book sets out to provide students and technical people with an essentially practical account of the non-parasitic, virus, bacterial, and fungus diseases of cultivated plants in Italy, and it achieves its object admirably. The author avoids academic discussion and theorizing, and the information given is accurate, up to date, and agreeably concise. The non-parasitic diseases are classified according to causes, bacterial diseases according to the symptoms, and fungus diseases under families and genera. Virus diseases are dealt with under hosts and comprise the least satisfactory part of the book. There are several introductory sections, including one on modern fungicides, with a compatibility table incorporated; a helpful and lengthy glossary; and a comprehensive index. The whole is illustrated by four original coloured plates depicting twenty-five diseases, and 190 photographs and drawings. The photography is reasonably good but scarcely does justice to the excellence of the text. Most of the diseases dealt with are common to many countries, and it is instructive to compare their relative importance and the emphasis given to them in Italy with the position, for instance, in the United Kingdom.

W. C. MOORE

SOIL EROSION

The Conservation of Natural Resources, *by R. C. Haw. Pp.* 256. *Faber and Faber Ltd, London.* 1959. 30*s. net.*

The author is an instructor in soil and water conservation at the Domboshawa School in Southern Rhodesia, and he has had a wide experience of conservation problems in Central, East, and South Africa. His book opens with an eloquent and moving picture of the inroads of soil erosion that he has watched and the losses of fertile land that this entails. Natural erosion is one of the major factors in geological evolution, but in many places it is being accelerated by man's activities, and this can be largely avoided by better farming practices, as in the successful Tennessee Valley Authority experiment in the Mississippi Valley.

The present study differs from most of the books describing the ravages of soil erosion in that the greater part of it is devoted to the practical details of the techniques for conserving both soil and water. It has been written with the object of helping farmers to appreciate the methods by which soil erosion can be checked. Naturally, in a volume of this size the engineering and agricultural practices involved can be described only in outline, but the account of these is clear and convincing, and it is supplemented by a useful bibliography and an appendix dealing with the plants specially suited to soil conservation. The fruits of the author's experience are applicable over a much wider field, especially in the tropical and subtropical regions of the world, and farmers will find his book a most valuable guide.

H. HARTLEY

BINARY ALLOYS

Constitution of Binary Alloys (*second edition*), *by M. Hansen, with the co-operation of K. Anderko. Pp. xix+1305. McGraw-Hill Book Co. Inc., New York; McGraw-Hill Publishing Co. Ltd, London.* 1958. £12 12*s. net.*

A knowledge of the appropriate phase diagram is a necessity in any investigation involving the properties of alloys, and few reference books can have been consulted more extensively than Hansen's *Der Aufbau der Zweistofflegierungen.* This comprehensive survey of information on binary diagrams was published in 1936 and has inevitably decreased in value, but no later compilation has effectively replaced its careful and critical assessment of data. An outstanding welcome from all metallurgists and many other scientists is thus assured for this second edition, which is a completely rewritten book.

Some idea of the problems facing the authors is given by the increase in the number of systems covered (1334 instead of 828), in phase diagrams reproduced (717 instead of 456), and in references consulted (9800 instead of 5500). This has necessitated a terser style of writing, and detailed comparisons of the relative merits of different investigations are no longer given, although great care has been taken to select and recommend the best data. Phase diagrams are now plotted with composition scales marked linearly in atomic percentages; non-linear weight percentage scales, and tables to facilitate rapid and accurate interconversion are also supplied; the diagrams are beautifully drawn and reproduced. The book is very highly recommended.

J. W. CHRISTIAN

METALLURGICAL DICTIONARY

A Dictionary of Metallurgy, *by A. D. Merriman. Pp. xv+401. Macdonald and Evans Ltd, London.* 1958. £6 6*s. net.*

The effort which has gone into 'A Dictionary of Metallurgy' is obviously quite considerable, painstaking, and reliable, but, having submitted some 50 current metallurgical terms to this 'dictionary' to test it, I formed the opinion that it would have been better termed a glossary. Furthermore, the book claims to be up to date and gives some examples from the nomenclature of atomic energy. Consideration of references to one of the newer metals, titanium, indicates that 1953 to 1954 was the dead-line in this field. It should be made clear as to how up to date the references are in the various metal fields. For research workers it is not encyclopaedic enough in its reviews, but for metallurgists it can be reasonably helpful on the mineral and extraction side. It should also be noted that little treatment is given to terms used in discussing theories of the metallic state on the one hand, or to metallurgical terminology connected with, say, modern melting techniques, rolling, jointing (particularly welding),

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or X-ray examination on the other. Despite these limitations, some 7000 current words are covered.

The compilation of this book certainly justifies further intensive work with a view to producing a comprehensive encyclopaedia of metallurgical terms. For those very much on the outer fringe of metallurgy, who would like a first source of reference, it is useful, particularly because so far as I know there is no similar work available in the English language.

W. O. ALEXANDER

HISTORY OF SCIENCE

Patterns of Discovery, *by N. R. Hanson. Pp. ix + 241. Cambridge University Press, London.* 1958. 30*s. net.*

In his introduction Professor Hanson states that 'the issue is not theory-testing but theory-finding', his concern 'is not with the testing of hypotheses, but with their discovery'. His book is thus a welcome break-away from the stream of studies inspired by the schools, whether of Wittgenstein or of Carnap, of philosophical analysis. Not that Hanson (or the reviewer) would for a moment deny the value of the clarification of the logical structure of existing knowledge which these studies have achieved; but by an over-emphasis of the hypothetico-deductive element in 'completed' systems they have, he implies, left out of account the structure of creative thinking. By an admirable study of the origins of terrestial and celestial kinematics at the hands of Galileo and Kepler respectively he introduces this missing element of the 'conceptual foundations'. Of the greatest importance in this part of his work is his demonstration, by argument and graphic illustrations, of the ambivalence of mere perceptual 'data' unless biased by a precedent interpretative scheme—a fact well known to psychologists, as he shows by an extensive range of references, but too often ignored by philosophers. The main part of the text concludes with an effective application of these views to the elucidation of the paradoxes and perplexities of the physics of elementary particles.

Professor Hanson writes with great gusto; every page challenges critical appreciation. Though it may be questioned how far the scope of the inquiry covers science, this is a book which no one whose interest in scientific endeavour extends beyond routine can afford to miss. The sixty pages of critical and bibliographical notes at the end reveal the prodigious industry of the author and provide a guided stimulus to further research by the reader.

W. P. D. WIGHTMAN

HISTORY OF TECHNOLOGY

A History of Technology, *Vol. IV.* The Industrial Revolution *c.* 1750–*c.* 1850, *edited by Charles Singer, E. J. Holmyard, A. R. Hall, and Trevor I. Williams. Pp. xxxiv + 728. Clarendon Press, Oxford.* 1958. £8 8*s. net.*

This volume really marks the climax of the history of technology. During the century which it covers, technology, increasingly influenced by and influencing science, finally came to establish genuinely industrial societies. While the earlier volumes cast their net widely over the world, this one now draws it tightly round events in the West. Like its predecessors, it is made up of chapters on a variety of different subjects, as the material demands. Written by different experts, the chapters are grouped under larger headings. There are some 350 line drawings, 48 plates (of which many contain more than one illustration), and workable indexes of personal names, place-names, and subjects.

The first group of chapters, forming Part I, deals with primary production, and covers agricultural methods and machinery, fish preservation and whaling, and the mining and processing of coal, iron, and the non-ferrous metals. These chapters thus describe the primary means by which the rapidly rising populations of industrial countries were fed and clothed, and by which industry was supplied with what became its main source of energy—coal—and with the metals of which its machines and many of their products were made. Part II gives an account of the forms of energy exploited, attention being given to quantitative comparisons, and here is to be noted the considerable development of the water-mill, which was only slowly replaced by the improved designs of reasonably efficient steam-engines burning coal. Part III covers manufacture, and includes the rise of the early chemical industry (at first a mainly French achievement), the making of gas for light and heat, the textile industry, ceramics and glass, and the rapid improvement in the design and construction of precision instruments (essential for science as well as for accurate control of advanced industry) and machine tools. Part IV takes us into another part of the field, the application of the new industrial products and methods in the construction of buildings and bridges, especially of iron, and in the engineering of water supply and sanitation which the growth of large industrial towns made imperative. Part V moves on to communications—roads, canals, ships, cartography, dredging, and telegraphy. The volume is brought to a close by a brief essay on the change in character from technology based on the empirical crafts, as in the earlier volumes, to technology based on science, as it broadly was by the middle of the nineteenth century.

Two large historical issues are involved in the subject of this volume. The first is interaction between technology and science. Some indication is given of the scientific advances that influenced technology. (Here we may note the blemish that James Watt is wrongly said to have 'independently discovered the phenomenon of latent heat of steam'—page 182.) But considerations of space have entirely squeezed out any discussion of the second large historical issue, the relation of technology to economic and social structure and policy and to the demands of trade and war. Although they do get a brief treatment in the next, and final, volume, what is really required is that some historian should use the material supplied in these volumes to write a full analytical essay on these themes, at the same time relating the history of technology to the history of science and its institutions of education and research.

A. C. CROMBIE

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Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

Quantum Particle Dynamics, *by J. McConnell. Pp. xi+252. North-Holland Publishing Co., Amsterdam.* 1958. 40*s. net.*

The aim of this book is to provide a background for those who have no previous acquaintance with relativity and quantum theory, so that they can gain sufficient knowledge of quantum and meson theory to understand the main features of the theory of elementary particles. The treatment is mathematical, but presumes no more than a working knowledge of calculus and of elementary algebra, and the book is intended for advanced students and research workers. It includes chapters on quantum theory, wave mechanics, matrix mechanics, the Dirac equation, nuclear forces, and mesons and nucleons.

Expansion Machines for Low Temperature Processes, *by S. C. Collins and R. L. Cannaday. Pp.* 116. *Clarendon Press, Oxford; Oxford University Press, London.* 1958. 12*s.* 6*d. net.*

There is in this book a brief description of the development of engines for refrigerative use, and chapters on engines and turbines for gas liquefaction, and on expansion engines in low-temperature systems; it is these engines that are in part responsible for the striking increase in research in low-temperature science. The book also deals with some applications of these machines.

Physics of Meteor Flight in the Atmosphere, *by E. J. Öpik. Pp. viii+174. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London.* 1958. *Paper covers,* 15*s. net; bound,* 30*s. net.*

The phenomena occurring during the flight of a meteor through the terrestrial atmosphere are dealt with in this book, with the intention of providing a basis for further research. The subjects covered include the classification of meteors, meteoroid energy transfer, ablation, and atomic collisions. The last chapter mentions some applications, referring to the Draconids and the naked-eye meteors.

Free Radicals, *by A. F. Trotman-Dickenson. Pp. viii+142. Methuen & Co. Ltd, London; John Wiley & Sons Inc., New York.* 1959. 12*s.* 6*d. net.*

The greater part of this book concerns the quantitative aspects of elementary reactions involving radicals, although the whole field of free radicals is briefly surveyed, including the physical properties of free radicals, and the experimental methods used in their study. There is a chapter on the reactions of the biradicals.

Nouveau traité de chimie minérale, *edited by P. Pascal. Vol. XII, pp. xxxix+692; Vol. XIX, pp. xxxix+953. Masson et Cie, Paris.* 1958. *Vol. XII: paper covers, fcs.* 6000; *bound, fcs.* 7000. *Vol. XIX: paper covers, fcs.* 8500; *bound, fcs.* 9700.

Volume XII has chapters on vanadium by A. Morette, on niobium and tantalum by R. Rohmer and M. Foex, and a shorter section on protoactinium by G. Bouissières and M. Haïssinsky. The physico-chemical characteristics of the elements have become better known since the last edition, which has made possible their more systematic arrangement, and is has also become possible to eliminate some dubious compounds, and to show more fully the relationships between these elements and their neighbours in the Periodic Table.

Volume XIX—there are to be twenty volumes in all—is concerned with the six platinum metals. The section on ruthenium and osmium is by R. Charonnat, and G. Ciepka and P. Poulenc have written on rhodium. The articles on iridium by M. Delépine and on palladium and platinum by Cl. Duval are reprinted from the previous edition.

Endocrine Control in Crustaceans, *by D. B. Carlisle and Sir Francis Knowles. Pp. vii+120. Cambridge University Press, London.* 1959. 21*s. net.*

Certain body functions in crustaceans are controlled by chemical substances, manufactured by cells in the nervous system and elsewhere, that are carried by the blood-stream. This book discusses the studies that have marked significant advances in the knowledge of this endocrine control. An extensive list of references is included.

Einführung in die Vektorrechnung für Naturwissenschaftler und Chemiker, *by H. Sirk. Pp. xi+124. Verlag von Dr Dietrich Steinkopff, Darmstadt.* 1958. DM 16.

Many fields of science use vector mathematics, and this book is intended to provide a basic knowledge of this branch of mathematics. It starts from the fundamental principles and covers the elements of vector algebra and vector fields. Examples of the vectorial approach to problems in crystallography, chemistry, physics, and meteorology are included, together with some examples from electrocardiography.

Biographical Memoirs of Fellows of the Royal Society, *Vol. IV. Pp.* 359. *The Royal Society, London.* 1958. 30*s. net.*

Accounts are given of the lives and achievements of twenty-seven Fellows who died during 1957–58. Each memoir is preceded by a full-page photograph and followed by a bibliography of the deceased Fellow's published works.

Le Leggi della Vita, *edited by G. Enriques, E. Macorini, and G. Pampaloni. Pp.* 687. *Nicola Zanichelli Editore, Bologna.* 1959. *Lire* 5800.

This volume forms part of a series of general biological works, and is a copiously illustrated semi-popular encyclopaedia of biology comprising general articles by various contributors on the discovery of the living world, cytology, the biological functions of organisms, environment and life, animal behaviour, and control in biology. One section provides a chronology of the biological sciences, general tables and diagrams of biological interest, and a 193-page dictionary of biological terms.

Gli Atomi e la loro Energia, *by E. Persico. Pp. xvi+490. Nicola Zanichelli Editore, Bologna.* 1959. *Lire* 5500.

The book contains two sections, the first covering atomic physics and the second nuclear physics. The treatment is essentially theoretical, but acquaintance with mathematics beyond elementary differential and integral calculus is not required. The introductory chapters deal with the Bohr-Sommerfeld theories of the atom, leading up to modern views of quantum and wave mechanics. The nuclear physics section discusses the basic phenomena of radioactivity and gives an account of recent applications of nuclear fission.

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Notes on contributors

H. C. VAN DE HULST,
Ph.D.,

Was born in Utrecht, Netherlands, in 1918 and received his doctor's degree at Utrecht University in 1946, and is now professor of astrophysics at Leiden University. Has published 'Light scattering by small particles' and many articles on astronomical subjects, dealing with the solar corona, the zodiacal light, interstellar dust, the interstellar gas, and radio-astronomy. He received the Henry Draper Medal and the Eddington Medal for his prediction of the 21-cm line and for his work in this field with the Leiden group.

J. W. ATZ,
B.A., M.Sc., Ph.D.,

Was born in 1915 and educated at Cornell and New York Universities. He joined the staff of the New York Aquarium, New York Zoological Society, in 1937 and has worked for that institution ever since, with the exception of nearly six years' military service with the United States Army. He was appointed Assistant Curator in 1947 and Associate Curator in 1957.

G. E. PICKFORD,
Ph.D.,

Was born in England in 1902. After leaving the University of Cambridge she spent three years as Mary Ewart Travelling Scholar, studying earthworms in South Africa. She went to Yale University and submitted a monograph on this subject as a doctoral thesis (1931). In 1934 she joined the staff of the Bingham Oceanographic Laboratory at Yale and has been associated with this institution ever since, and she was appointed Research Associate in 1946. She taught at Albertus Magnus College, New Haven, Conn., from 1934 to 1948. She studied Octopoda from various parts of the world, and has published several papers on the subject, on the Vampyromorpha, an archaic group of deep-sea cephalopods. She began experimental work on fish endocrinology in 1947 and has specialized in this field during the past twelve years.

C. R. AUSTIN,
D.Sc., B.V.Sc.,

Was born in 1914 in Sydney, Australia, and educated at Eastbourne College, England, and Sydney University. He was a member of the research staff of the Commonwealth Scientific and Industrial Research Organisation, Australia, from 1938 to 1954, investigating biochemical aspects of pregnancy toxaemia in sheep, the development of special operational and emergency rations for troops, and the physiology of reproduction. He joined the research staff of the Medical Research Council, England, in 1954. He is currently engaged in research on mammalian fertilization and associated phenomena. He has been a Secretary of the Society for Endocrinology since 1956.

E. C. AMOROSO,
Ph.D., M.B., B.Ch., B.A.O., F.R.S.,

Graduated in medicine at University College, Dublin, and studied at the *Kaiser Wilhelm Institut für Zellforschung*, Berlin, the University of Freiburg, and University College, London. In 1929 he was awarded the McArdle Medal in Surgery and a travelling fellowship in science at the National University of Ireland. He was appointed to the Royal Veterinary College, University of London, in 1935, and has been Professor of Physiology since 1948. His main interest in research is the structure and function of the placenta, and the physiology of reproduction, on which he has published extensively.

D. McKIE
Ph.D., D.Sc., F.R.I.C., F.R.S.E.,

Was born in 1896. He entered University College, London, in 1920 and graduated in chemistry, and is now Professor of the History and Philosophy of Science in the University of London. He has written extensively on the history of chemistry, including an authoritative book on Lavoisier's life and work.

J. SUTTON,
Ph.D., F.G.S.,

Was born in 1919 and was educated at King's School, Worcester, and Imperial College, London. Following war service as a radar officer, he returned to Imperial College in 1947 to carry out research on the Pre-Cambrian rocks of Loch Torridon. He has worked subsequently on crystalline rocks of many other parts of the Scottish Highlands. In 1948 he joined the staff of Imperial College, was appointed Reader in Geology in 1956, and since 1958 has been Professor of Geology.

C. E. HUBBARD,
O.B.E., F.L.S.,

Was born in Appleton, Norfolk, in 1900 and was educated at the King Edward VII Grammar School, King's Lynn, and Chelsea Polytechnic. In 1920 he started work at the Royal Botanic Gardens, Kew, subsequently transferring to the Herbarium to specialize on the *Gramineae* (grasses) under Dr Otto Stapf. He spent 1930–31 revising the grass collections of the Queensland Government. He has published extensively, mainly on the British, African and Australian grasses. In 1957 he was appointed Keeper of the Herbarium-Library, Kew, and became Deputy Director of the Gardens in 1959.

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A century of spectrochemistry

Spectrochemistry effectively began a hundred years ago, with the invention of the flame spectrometer by Bunsen and Kirchhoff in 1859: this very quickly led to a whole series of outstandingly important results, not only in chemistry but in astronomy. Some of the possibilities had, however, been foreseen by earlier workers. Thus T. Melville, as early as 1752, noted the yellow colour given to flames by the introduction of sodium compounds, and A. S. Marggraf, in 1758, mentioned the lavender potassium flame. Herschel added to the list the crimson flame of strontium compounds and the green of copper compounds and borates, and suggested the possibility of detecting small quantities of elements by this method. Fox Talbot, in the 'Philosophical Magazine' in 1834, described the use of a prism to distinguish between the carmine red imparted to a flame by lithium compounds and the crimson of strontium. 'The prism displays between them the most marked distinction that can be imagined. The strontia flame exhibits a number of red rays well separated from each other by dark intervals, not to mention an orange and a bright blue ray': lithium, he recorded, gave a single red 'ray'. He, too, was impressed by the minute quantities needed for what he called 'optical analysis'. Such simple flame-tests are still standard procedure in inorganic analysis.

It was, however, Kirchhoff who established the fundamental principles of spectrum analysis: Kirchhoff was, as Roscoe put it, the most important discovery made by Bunsen during his stay at Breslau. When Joly moved to Munich, Bunsen arranged for Kirchhoff to become professor of physics at Heidelberg: the partnership thus started in 1854 was immensely fruitful.

The first flame spectrometer was constructed by Kirchhoff in 1859. The essential features were a bunsen burner—previous workers had used the less efficient spirit lamp—a hollow glass prism filled with carbon disulphide, and a simple viewing telescope (an improvement introduced by Fraunhofer) with a wavelength scale reflected into it by means of a mirror. This simple instrument was used for the identification of a long list of new elements, and also to establish the relationship between emission and absorption spectra.

Absorption spectroscopy may be said to date from Wollaston's observation of dark lines in the Sun's spectrum, though it was Fraunhofer, in 1814, who first charted these systematically. Fraunhofer noticed that a prominent black line—he called it the D line—in the Sun's spectrum appeared in the same position as the yellow line of a sodium flame, but he did not appreciate the significance of this. Kirchhoff, in 1859, showed that the dark lines could be produced by placing a sodium flame between a light source and the spectrometer slit: similarly, a sodium flame placed in front of the slit would intensify the D lines in the solar spectrum. From these observations, Kirchhoff concluded that there must be sodium in the Sun's atmosphere. It was, Bunsen wrote, a research that 'gives us sleepless nights', for the method could reveal the composition not only of the Sun but of other stars with the same certainty as chemical methods gave with terrestrial substances. Kirchhoff's memoir of that year to the Berlin Academy was concerned with the spectra of elements, the reversal of spectral lines, the constitution of the Sun's atmosphere, and physical aspects of the solar spectrum.

Kirchhoff as a physicist was ideally complemented by Bunsen as a chemist: the latter abandoned much of his other work in order to collaborate with Kirchhoff. 'Don't be angry with me, dear Roscoe, if I have still done nothing more on our photochemical work', he wrote in 1860, when they were busy at Heidelberg trying to separate a fourth alkali metal—sodium, potassium, and lithium were already known. Although they knew that their method was extremely sensitive, for they had detected lithium in twenty grains of sea water, they doubted if they would be able to isolate enough of the new element for an orthodox chemical investigation. However, they were, as Bunsen put it, 'fortunate': 'persevering' would be a more appropriate word. They evaporated to dryness forty tons of mineral water from Dürkheim, removed the alkaline earths and most of the lithium from the residue, and examined it with their spectrometer. They identified the lines of sodium, potassium, and lithium, and also two blue lines very close together. As there was no element known to give such lines, they concluded that they had discovered a new alkali metal: they called it caesium, from a Latin word for blue. They isolated 50 grams of caesium chloroplatinate from the concentrated residue, and established the principal chemical properties of the element with the 17 grams of caesium chloride that finally resulted:

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twenty years later Setterberg prepared the free metal by electrolysis. Caesium was the first element whose existence was discovered spectroscopically.

Rubidium, the fifth alkali metal, was discovered very soon after caesium, the discovery being reported to the Berlin Academy in 1861. To obtain it, impure potassium platinichloride, prepared from lepidolite, was repeatedly washed with boiling water. Gradually the potassium lines in the spectrum weakened and two violet lines became stronger; new lines appeared, including the two brilliant red lines that gave the name to the new element.

The application of Bunsen and Kirchhoff's techniques quickly led to the identification of more new elements. William Crookes was keenly interested in the new technique. Needing some tellurium for a series of experiments, he decided to try to extract it from some selenium purification residues. Tests indicated the presence of tellurium in the material, but Crookes was unable to extract any and decided to look for the element spectroscopically. A portion of the residue gave a spectrum of selenium and, as this became fainter, he expected the tellurium spectrum to appear: instead, 'a bright-green line flashed into view and quickly disappeared'. Crookes was able to eliminate the presence of all but five elements from the residues; he examined the spectra of these elements and of some of their compounds and found no trace of the green line. He therefore concluded that it was due to a new element; he called it thallium, from the Greek word for a green shoot. He reported the discovery in 1861 in his 'Chemical News'.

Other new elements quickly followed. Indium was discovered by R. Reich and T. Richter in 1863 and gallium (the name is a patriotic tribute by the discoverer), samarium, and dysprosium by L. de Boisbaudran. The existence of ytterbium, holmium, and neodymium also was discovered by spectroscopy. Bunsen himself mapped the spark spectra of these and other rare-earth elements, but in these researches he was doubly unfortunate. Firstly, he was unaware of the effects on the spectra of this different form of excitation; secondly, the original manuscript was destroyed, ironically, by a fire caused by the focusing of the Sun's rays by a water-bottle.

Meanwhile a startling result had followed Kirchhoff's use of the spectroscope to reveal the presence of sodium in the Sun. The discovery started in 1868 with the identification by Janssen of a third line, which he called D3, close to the sodium lines D and D2, in the spectrum of the Sun's chromosphere; Lockyer—who independently identified this line a few days later—and Frankland ascribed this line to an element, unknown on the earth, which they called helium. Not for several years was helium found on the earth, although had he had greater luck Hillebrand might have made the discovery almost at once. In an investigation of cleveite, a uranium mineral, he found that on heating it an inert gas was evolved. This he wrongly identified as nitrogen—it was in fact largely helium—although in a spectroscopic examination he came very close to attributing certain spectral lines to a new element. Subsequently, Miers drew Ramsay's attention to this work and the latter identified Hillebrand's 'nitrogen' as a new gas which he tentatively called krypton. In March 1895 Ramsay left a sample with Crookes, who a week later telegraphed 'krypton is helium'. Ramsay in his turn telegraphed to Berthelot, whom he was due to meet in Paris a few days later, saying '*Gas obtenu par ma cleveite melange argon helium. Crookes identifie spectre. Faites communication academie lundi.*'

The discovery of helium in the Sun involved no new principle, but it greatly stimulated spectrometric analysis of the light of the Sun, planets, and stars, and this line of research quickly resulted in the gaining of a wealth of new astronomical knowledge of a kind that could not have been imagined in 1859. It proved capable of giving information not only about the composition of the Sun and stars but about much else beside. It confirmed, for example, that the planets shine by reflected sunlight.

In 1824 Fraunhofer found the spectrum of Sirius to be different from that of the Sun. In 1833 Brewster showed that certain of the Fraunhofer lines in the solar spectrum became stronger when the altitude of the Sun was low, while others were not affected. He thus proved that some of the Fraunhofer lines were of atmospheric origin. William Huggins made a survey of the spectra of the stars and nebulae visible from London, and it was found that they could be classified according to the characteristics of their spectra. He made, in 1867, pioneer measurements of line-of-sight velocities of a few stars from the Doppler displacement of their spectral lines, and in the same year showed, from their spectra, that some of the nebulae are gaseous. Huggins, again, was among those who suggested the use of the spectroscope for observation of the Sun's prominences at periods other than those of eclipse: in recent years this kind of research has led to important new knowledge of solar phenomena.

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The biochemistry of the mammary gland

J. M. BARRY

This article reviews recent work and summarizes what is known of the biochemistry of the mammary gland when it is fully developed and secreting milk. It considers what compounds the lactating gland absorbs from the blood, what chemical reactions they undergo in the secretory cells when milk is made, and what proportion of the fat, protein, and lactose of milk, and of the energy requirements of the gland, are derived from each of these compounds.

The secretory cells of the mammary gland are all of one type and continuously make milk from components of the blood, the milk being stored within the gland until removed. The three main components of milk are fat, proteins, and milk sugar or lactose, and these differ from any of the corresponding components of blood. It also contains smaller amounts of inorganic substances and traces of many other organic compounds; the latter include vitamins, most of which are found also in blood. The milk of cows and goats usually contains 3–5 per cent each of fat, proteins, and lactose; human milk has less protein and more lactose.

Our knowledge of the biochemistry of the mammary gland is becoming more comprehensive than that about any other organ of the body. Not only do we know many enzymatic reactions that occur in the gland, but our information is quantitative, which is still rare in biochemistry. We have gone a long way towards discovering which compounds the gland absorbs from the blood and in what relative amounts, and in finding out what proportion of each of these compounds passes along each pathway of metabolism. All this is possible largely because of the structure of the gland. The blood leading to and from it can be easily tapped, and most of the products of its metabolism are not returned to the blood, as in other organs, but are secreted into the milk. As a result, quantitative experiments with isotopic tracers or by arterio-venous measurements are relatively easy to perform.

When we consider which compounds of blood could possibly be important metabolites of the mammary gland, we have, fortunately, to take account only of those whose concentration lies above a minimum which, at least for the cow and goat, can be calculated. A number of measurements show that approximately 500 litres of blood flow through the gland of a cow for each litre of milk secreted [1]. This figure is rough, but we can be almost certain that the true value is always below 1000. If we assume the value of 500 to be correct, then, if 5 g of any compound of blood is to be available for the formation of a litre of milk, its concentration in blood must be at least 10 mg per litre. Cow's blood contains around 500 mg of glucose per litre, and glucose could therefore be an important metabolite. On similar reasoning, many other compounds can be excluded. The careful analyses of W. H. Stein and S. Moore [2] show that peptides of blood can at best provide less than 10 per cent of each amino-acid of milk proteins. Propionic and butyric acids, which are absorbed in large amounts from the cow's gut, are present in such low concentrations in arterial blood that they could each provide only about 1 g for every litre of milk—an insignificant amount [3].

The metabolism of the mammary gland varies between species. The variation is most marked between ruminants and other mammals, as has been clearly shown by some experiments of S. J. Folley and his colleagues at Reading. They measured the rates at which thin slices of lactating mammary glands absorbed oxygen when suspended in salt solutions to which various organic compounds had been added. It was found that the rat's mammary gland can oxidize glucose more rapidly than it can acetate, whereas the sheep's gland oxidizes acetate more rapidly than glucose [4]. This difference between ruminants and other mammals is clearly related to their digestion: ruminants absorb large quantities of acetate from their alimentary canals but almost no glucose. We might guess that this is a genetic difference in tissue metabolism, but this does not in fact seem to be true. The evidence suggests that the difference is induced in the young ruminant by the products of digestion as its food changes from milk to herbage, and that a similar change could be induced in other animals by giving them food containing much fat and little carbohydrate.

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PROTEINS

The principal proteins of milk are casein and β-lactoglobulin, and we have recently made great advances, by using isotopic tracers, in discovering which compounds the mammary gland takes from the blood to make the proteins of milk. Proteins are composed of amino acids that are of two types: essential, which, roughly speaking, cannot be made in the body, and non-essential, which can. The only possible sources of the essential amino acids of milk proteins are the same amino acids free in solution in the blood or combined in plasma proteins. T. S. Work and his colleagues in London, and my colleagues and I at Oxford, have tried to discover what proportion of the essential amino acids of casein and β-lactoglobulin come from each of these sources [5]. These experiments originated in an attempt to discover whether tissue proteins could be made from plasma proteins without intermediate hydrolysis to free amino acids. Since then, it has become clear that every protein has its own peculiar amino-acid sequence, which is usually quite unlike that in any other protein, and it is therefore highly unlikely that one protein can be converted to another without complete dismantling of the amino-acid chains. The possibility remains, however, that tissues can obtain supplies of amino acids by hydrolysing plasma proteins, and the mammary gland is one of the few organs of the body in which this possibility can be tested.

Arterio-venous measurements had previously shown that free amino acids are absorbed by the lactating mammary gland of cows and goats in significant amounts, but the concentration of proteins in blood plasma is so high that even if some were absorbed by the gland the arterio-venous difference would be undetectable. Work and I did experiments in which we injected certain essential amino acids, which had been labelled with radioactive carbon, into the blood-stream of lactating goats and rabbits. For a few hours after each injection, the free amino acids of the blood were highly radioactive, while the plasma proteins contained little activity. Casein and β-lactoglobulin obtained from milk samples taken during this time were highly active. This suggested that a significant part of their essential amino acids had come from the free amino acids of blood and not from plasma proteins, although there remained the possibility that the radioactive amino acids had been rapidly incorporated into a small fraction of the plasma proteins in the liver before being absorbed by the mammary gland. I was able to exclude this possibility by showing that the same results were obtained when an isolated mammary gland was perfused with blood. In a quantitative experiment with tracers I was able to show that at least 70 per cent of each of two essential amino acids in casein came from the same two free amino acids in blood. No experiments have disproved that plasma proteins provide a small proportion of the amino acids of casein and β-lactoglobulin, but there is no evidence in favour of it.

At Oxford we have also tried to find whether the non-essential amino acids of casein also come directly from the blood or are formed within the gland from other compounds. We found from experiments with radioactive amino acids that, in the goat, at least 70 per cent of the glutamine and the glutamic acid and at least 50 per cent of the asparagine and the proline of casein come from the same amino acids in solution in the blood. These results show, incidentally, that glutamine and asparagine are incorporated into proteins as two amino acids quite distinct from glutamic and aspartic acid. This fact is important, and is not always remembered when attempts are made to discover what sequence of bases in genetic deoxyribonucleic acid causes a particular sequence of amino acids in a protein. Experiments with labelled glucose show that less than 20 per cent of the glutamine and glutamic acid, and less than 17 per cent of the asparagine and aspartic acid, are made within the gland from blood glucose. Arterio-venous measurements also revealed a large absorption of free serine from the blood [5].

It is therefore clear that the non-essential amino acids of casein mainly come direct from the blood. The enzymes for making them do nevertheless seem to be present in the gland, for M. Kleiber and his colleagues [6] have shown that if radioactive acetate is injected into one quarter of a cow's udder, the non-essential amino acids in milk proteins from that quarter become more radioactive than those from other quarters.

Further, H. G. Wood and his colleagues have recently shown that some serine is formed from blood glucose within the gland [7]. These workers injected radioactive glucose into the artery leading to one half of the udder of a cow and, by draining away the venous blood for a few minutes, prevented almost all the glucose which was not absorbed by that half reaching other tissues. Like a perfusion, this ingenious technique allows us to study the chemistry of the gland uncomplicated by that of other tissues but, unlike a perfusion, leaves the gland functioning normally. They were able to conclude

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that about 25 per cent of the carbon of serine in casein came from the carbon of blood glucose.

Tracer experiments on the other proteins of milk show that α-lactalbumin is formed, largely at least, from free amino acids of the blood, but that the immune globulin and serum albumin of milk come from the blood without change. However, the immune globulin of cow colostrum (the milk formed in the first few days of lactation) seems to be made from free amino acids by plasma cells held in the mammary gland [5].

FATS

The milk fat of most mammals, as shown by the analyses of T. P. Hilditch, has a composition very similar to that of the remainder of their body fat. That of ruminants, and of some other herbivores, however, contains a high proportion of short-chain fatty acids with 4, 6, 8, 10, 12, and 14 carbon atoms—acids which are almost entirely absent from their own fat depots and from those of other mammals. In the fat of cow's milk about 30 per cent of the fatty acid molecules have these short chains [8]. There are also, surprisingly, traces of acids with 7, 9, 11, 13, 15, and 17 carbon atoms, which are rarely found in nature [9]. We might expect to find, in cow's milk, that each triglyceride molecule contains only short- or only long-chain acids, but in fact most of them contain fatty acids of each type.

A great deal has been discovered about the compounds which the mammary gland takes from the blood to provide the fat of milk, but much still remains unclear. Firstly, it seems certain that in ruminants all, or a large part, of the long-chain stearic and oleic acids in milk fat come directly from the blood. The evidence for this is that when labelled stearic acid, either free or combined in triglycerides, was fed to cows or goats, up to 60 per cent was recovered as stearic and oleic acid in milk fat. When triglycerides containing labelled stearic acid were injected into a cow's bloodstream, a large proportion of the label was recovered in the milk fat. Further, injection of labelled glucose and acetate into a cow has shown that little stearic and oleic acids are formed in the gland from these precursors. However, in precisely what chemical form the stearic and oleic acids pass from the blood to the secretory cells is not clear, and clarification of this question might give important information about the transport of fatty acids to tissues. R. F. Glascock at Reading has recently discovered that when labelled stearic acid in triglycerides was fed to a cow it was partly carried to the milk in a small fraction of the blood which did not exchange with the bulk of the stearic acid of blood fat [10].

It is clear that part of the short-chain fatty acids of ruminant's milk are synthesized in the gland from acetate normally present in the blood of these animals. Thus, there is a significant arterio-venous difference in acetate across the glands of lactating cows. Slices of the glands of ruminants respire rapidly in acetate solutions with a high respiratory quotient—a sign of fatty acid formation—and, in fact, rapidly incorporate labelled acetate into fatty acids. The perfused mammary gland incorporates labelled acetate into the fatty acids of chain length shorter than those of stearic and oleic. The origin of these acids has been further clarified by S. J. Folley, G. Popjak, and their colleagues, who injected labelled acetate into a goat and isolated each fatty acid of even chain length from samples of milk. The specific activities of these acids from the combined milk samples differed from one another, showing that some at least were not completely derived from acetate of the blood. Almost the least active was the 4-carbon acid. Those with 6, 8, and 10 carbon atoms also contained a chain of four atoms with this low activity, but the activity of their other carbon atoms was higher. It seems almost certain that of every ten molecules of the 4-carbon acid in milk fat, four were made in the gland from blood acetate and six were made from some other compound in the blood. It also seems almost certain that the 6-, 8-, and 10-carbon acids are made completely by the addition of blood acetate to the 4-carbon acid. However, it is just possible that an equal proportion of each of these acids comes from some other compound of the blood, since the specific activity of blood acetate was not followed in this experiment. Experiments with tracers show that this other compound, if it exists, is not stearic acid, oleic acid, or glucose. The specific activities of the 14- and 16-carbon acids were equal and were only about one-third of that of the 10-carbon acid. This suggests that two-thirds of these molecules in milk come from the plentiful 16-carbon acid of blood fat, and the remaining third are built up in the gland, like the shorter-chain acids. The activity of the 12-carbon acid showed that a small portion of it must also be made in a different way from the shorter-chain acids [4]. Also interesting is that the traces of fatty acids with odd numbers of carbon atoms in milk fat arise from the combination of acetate with traces of propionic acid from the blood [9].

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The origin of the glycerol of ruminant's milk fat is not clear, but H. G. Wood and his colleagues showed that in a cow about 17 per cent of the carbon of the glycerol was derived in the gland from blood glucose [7]. The fact that short-chain fatty acids, which are formed in the gland, are usually found on the same glycerol molecules as stearic and oleic, which are not formed in the gland, suggests a rapid exchange between glycerides and free fatty acids within the secretory cells. The origin of the milk fat of animals other than ruminants has not been studied in great detail, but rats and rabbits form some fatty acids within the gland from blood glucose [10].

LACTOSE

Lactose is a disaccharide (figure 1). There is a significant arterio-venous difference in glucose across the mammary glands of cows and goats, and many investigators have shown that if glucose, labelled with carbon-14 in all carbon atoms, is injected into a cow or goat both the glucose and galactose of lactose become rapidly and equally labelled. By showing that glucose labelled only in carbon number 1 gave lactose in which the glucose and galactose were also labelled almost only in the same carbon, I was able to prove that this labelling did not come from decomposition products of the injected glucose in the blood. By injecting uniformly labelled glucose into a goat and comparing specific activities of blood glucose and lactose over several hours, O. K. Reiss and I concluded that over half of the lactose came from blood glucose. Similar experiments by Kleiber suggest that about 80 per cent of the lactose in cow's milk is made from blood glucose. There is also evidence that rabbits, guinea-pigs, and rats make lactose from blood glucose [11].

It is clear that cows and goats must use large amounts of glucose for lactose formation, but almost none is absorbed from the gut. Glucose is certainly formed from propionate, but the amounts absorbed from the rumen seem barely sufficient to provide all the lactose of milk. It is conceivable that there might be an inducible pathway by which an overall formation of glucose from acetate occurs, but this does not seem to exist. A very small proportion of radioactive acetate when injected into a cow appears in lactose, and the radioactivity is distributed in glucose as it is after injection into a rat. However, Kleiber has good evidence of formation of glucose from butyrate: a higher proportion of labelled butyrate than of

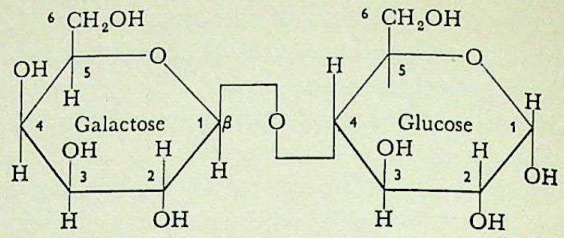

FIGURE 1 – *The structure of lactose* [4].

acetate is converted to lactose, and a lower proportion to milk fat [12].

Cell-free preparations of mammary glands can be made which will convert glucose to lactose, and many experiments have been done to discover the intermediate reactions. A key reaction is certainly the enzymatic conversion of uridine diphosphate glucose to uridine diphosphate galactose, demonstrated in mammary tissue by L. F. Leloir and H. M. Kalckar and their colleagues, following their brilliant experiments on glucose and galactose interconversions in other tissues. J. E. Gander, W. E. Petersen, and P. D. Boyer have good evidence that another fundamental step is the reaction of uridine diphosphate galactose and glucose-1-phosphate to give lactose-1-phosphate. The scheme for lactose formation shown in figure 2 has therefore been suggested.

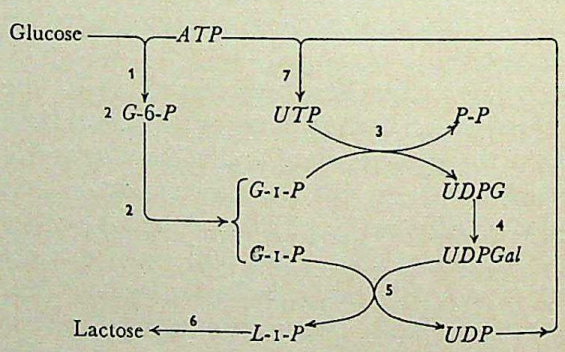

FIGURE 2 – *Suggested pathway for lactose synthesis. ATP, adenosine triphosphate; UDP, uridine diphosphate; UTP, uridine triphosphate; UDPG, uridine diphosphate glucose; UDPGal, uridine diphosphate galactose; P-P, pyrophosphate; G-1-P, glucose-1-phosphate; G-6-P, glucose-6-phosphate; L-1-P, lactose-1-phosphate* [11].

There are, however, difficulties in this scheme. It can be seen from figure 2 that both the glucose and galactose of lactose are regarded as derived solely from glucose-1-phosphate. Therefore, whenever isotopically labelled lactose is formed by the gland, the glucose and galactose should be identically labelled, provided they do not come from two different pools of glucose-1-phosphate in the secretory cells, which is just possible. If glucose

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that has been labelled equally with carbon-14 on every carbon atom is injected into a cow or goat, then the glucose and galactose of lactose do in fact have equal activities; but if the glucose is labelled only in carbon number 1, then the galactose usually has about 70 per cent of the activity of the glucose. This difference can be explained if the glucose molecules that are destined to become galactose are partially oxidized, and recombined to form fewer glucose molecules, by the reactions of the pentose phosphate cycle. However, the difference in activity shows that the scheme in figure 2 is at least partly incorrect. Again, Wood and his colleagues have shown that if radioactive acetate or glycerol is injected into the artery leading to one side of a cow's udder, traces of these compounds are incorporated into lactose, and the galactose has many times the activity of the glucose. He suggests that lactose is principally formed by the reaction of free glucose with uridine diphosphate galactose, the latter also being formed from blood glucose although the intermediates in its formation enter into side reactions. However, no enzyme has been found that catalyses this reaction, and therefore the mechanism of lactose formation is not yet fully understood [11].

CONCLUSION

Finally, what compounds are taken from the blood to provide energy for the gland; what proportion of the total energy does each provide; and how is each compound metabolized in the gland? We cannot yet answer these questions very fully. It seems certain that the glands of ruminants obtain the main part of their energy from substrates different from those of other mammals. It is almost certain that the ruminant gland obtains a large part of its energy by oxidizing blood acetate in the tricarboxylic acid cycle, but the proportion of the total energy which is obtained in this way is not known. There is evidence that the ruminant gland cannot convert glucose to acetylcoenzyme-A and hence oxidize it in the tricarboxylic acid cycle. Glucose is, however, slowly oxidized by slices of the gland, and this probably occurs by the pentose phosphate cycle [13]. The acetate which is absorbed by the gland of a cow during the formation of a litre of milk can be roughly assessed from arterio-venous measurements [14], and only a small fraction of this would be needed to provide energy for the synthesis of the proteins, lactose, and short-chain fatty acids in a litre of milk. However, the amount of carbon evolved as carbon dioxide during the formation of a litre of milk is about the same as the amount of carbon in the acetate absorbed [15]. Of non-ruminants, only the mammary gland of the rat has been studied in detail. Glucose is certainly a major source of energy here, and this can be oxidized via acetylcoenzyme-A and the tricarboxylic acid cycle, but a high proportion is oxidized by the pentose phosphate cycle [13].

Research into the biochemistry of the mammary gland has produced results of great fundamental interest, and this interest will be even greater when we can discover how the chemical reactions of the gland are regulated by the hormones which are carried to it in the blood. The prospect of further discoveries is good, for research into milk secretion is subsidized by medical and agricultural foundations in the wise belief that if we know how the gland works we will be better able to keep it in good order.

REFERENCES

[1] FOLLEY, S. J. *Biol. Rev.*, **24**, 316, 1949.

[2] STEIN, W. H. and MOORE, S. *J. biol. Chem.*, **211**, 915, 1954.

[3] ANNISON, E. F., HILL, K. J., and LEWIS, D. *Biochem. J.*, **66**, 592, 1957.

[4] FOLLEY, S. J. 'The Physiology and Biochemistry of Lactation' (first edition). Oliver and Boyd Ltd, London. 1956.

[5] BARRY, J. M. *Proc. roy. Soc., B*, **149**, 380, 1958.

[6] KLEIBER, M. and BLACK, A. L. 'A Conference on Radioactive Isotopes in Agriculture'. Atomic Energy Commission Report No. TID-7512. U.S. Government Printing Office, Washington. Pp. 395. 1956.

[7] WOOD, H. G., GILLESPIE, R., JOFFE, S., HANSEN, R. G., and HARDENBROOK, H. *J. biol. Chem.*, **233**, 1271, 1958.

[8] HILDITCH, T. P. 'The Chemical Constitution of Natural Fats' (third edition). Chapman and Hall Ltd, London. 1956.

[9] JAMES, A. T., PEETERS, G., and LAURYSSENS, M. *Biochem. J.*, **64**, 726, 1956.

[10] GLASCOCK, R. F. *Proc. roy. Soc., B*, **149**, 402, 1958.

[11] MALPRESS, F. H. *Ibid., B*, **149**, 362, 1958.

[12] ROGERS, T. A. and KLEIBER, M. *Biochem. biophys. Acta*, **22**, 284, 1956.

[13] GLOCK, G. E. and MCLEAN, P. *Proc. roy. Soc., B*, **149**, 354, 1958.

[14] MCCLYMONT, G. L. *Aust. J. agric. Res.*, **2**, 158, 1951.

[15] PETERSEN, W. E. and SHAW, J. C. *J. Dairy Sci.*, **25**, 708, 1942.

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Photography of the ocean floor

A. S. LAUGHTON

Although some underwater photographs were successfully taken as long ago as 1893, it is only recently that automatic cameras suitable for photography at depths of up to 3000 fathoms have been developed. This article describes one such type of camera, and discusses the information about the geology and zoology of the sea floor that has been obtained with it.

It was inevitable that, once the photographic method of recording pictures had become established, its use as a means of reproducing underwater scenes and the life of the sea should have been considered. The first serious efforts to take underwater photographs were made by Boutan in 1893, working in the clear waters of the Mediterranean off the coast of France. Although his only successful photographs were made by a diver-operated camera, he nevertheless foresaw the value of an automatic camera which could be lowered to the sea floor in places inaccessible to a diver. His failure in this field was due to the lack of suitable illumination and to the primitive nature of the apparatus then available.

Surprisingly enough, automatic underwater photography was not followed up until nearly fifty years later, although diver-operated cameras taking both still and ciné film had been extensively developed. In 1940, M. Ewing, A. Vine, and J. L. Worzel [1] successfully took photographs of the sea floor with a fully automatic camera. Under the stimulus of wartime needs, photography of the sea floor, especially of wrecks, and of sea-floor conditions for the purpose of sound propagation studies, became an established technique. After the war, it was quickly realized that this was a technique that could be used to investigate the great ocean depths and to observe the abyssal fauna and geology *in situ*. Following the American lead, many laboratories throughout the world have developed their own deep-sea cameras and have used them for a great variety of purposes.

CAMERA DESIGN

Fortunately for underwater photography, the wavelength for which the attenuation of light through water is a minimum lies in the middle of the visual range. In the deep sea we find that water has great clarity owing to the absence of suspended matter and that for ranges up to twenty feet or so no loss of definition of the image occurs. Thus a conventional camera viewing through a plain glass window with suitable illumination will give a good picture. There is, however, one optical problem that arises if high-resolution, wide-angle photographs are required. The path of light from water into air is refracted at an oblique interface, the refraction being a function of the wavelength. Hence, the angular field of view of the lens is reduced and, unless monochromatic light is used, the image off the axis is not sharp. The first effect is not important unless maximum coverage is required. The second effect can be corrected by placing in front of the camera a suitable lens that will introduce an equal amount of chromatic aberration in the opposite sense.

In the shallow water around the coasts and on the continental slope, the turbidity of the water is an important limiting factor. In many places, especially in harbours and river mouths where photography has important practical applications, the visibility is reduced to a foot or less and if photographs are required, a means has to be found of displacing the turbid water in the object field with clear water. This is a difficult practical problem and photography in shallow water is, therefore, of only limited use.

The practical design of a deep-sea camera can best be illustrated with reference to the one designed and built at the National Institute of Oceanography [2]. The camera consists of three basic units, the photographic unit, the flashlight unit, and the acoustic transmitter, or 'pinger' unit. Each of these has its own watertight casing and its own power supplies. The watertight cases are required to withstand external pressures up to 10 000 lb/in^2. The simplest cases for the purpose are cylindrical, and, in order to keep the overall weight to a minimum, an internal diameter of three inches was chosen. The cases are of light alloy, having a wall thickness of $\frac{3}{4}$ inch and being sealed throughout by O-ring seals. The window

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for the camera is made of Perspex in the form of a truncated cone $1\frac{1}{4}$ inches thick, in a conical seating.

The photographic unit comprises a lens and shutter, 15 feet of 35 mm film enabling a series of up to 100 pictures to be taken, and a motor and gearbox, driven by torch batteries, to move the film automatically after each exposure. This unit is shown in figure 1. The electronic flash unit is of conventional design working from dry batteries and generates 100-joule flashes. The pinger unit, which is triggered when a photograph is taken, transmits signals through the water to the operator on the surface telling him that the camera has reached the bottom. It is housed in one of the tubes forming the framework. Some such form of indicator is an important part of any equipment which is required to be lowered to the bottom of the deep sea, since it is impossible, in the presence of the additional tension due to up to three miles of wire hanging in the water, and the variations in tension due to the rolling and pitching of the ship, to feel the change in tension on the wire when the camera reaches the bottom. The pinger normally emits signals at a slow rate while the camera is in midwater, but when it touches bottom, the rate is increased.

The camera is triggered by a weight, combined with a small sampler, that is suspended below the camera. When this touches bottom, the flash, synchronized with the shutter opening, is triggered, the pinger signals the surface, and the film is moved to the next frame. The operator can immediately raise the wire several fathoms, so that the camera itself never touches bottom. After a minute or so another picture can be taken and the process repeated. A series of pictures can thus be taken while the ship drifts. In this way a photographic profile can be made of such deep-sea features as seamounts or the edges of abyssal plains. Any standard black and white or colour film can be used, and, if desired, stereoscopic pictures can be taken by using two separate photographic units. The underwater camera is shown in use on R.R.S. *Discovery II* in figure 2.

THE RESULTS OF PHOTOGRAPHIC EXPLORATION

During the past three years many hundreds of photographs of the sea floor, at depths varying from a few fathoms to nearly three thousand fathoms, have been taken by workers at the National Institute of Oceanography. The photographs have an immediate interest in revealing for the first time a part of the earth's crust never before seen by man, but their full scientific value cannot be realized unless they are related to the broader environment in which they are taken. Thus they should be taken in conjunction with a topographic survey of the area and with systematic sampling of the bottom by such means as coring and dredging, so that the details revealed in the photographs can be interpreted in terms of specimens that can be examined at close quarters. This, however, is a counsel of perfection and there is seldom time for all the necessary data to be acquired.

In reviewing the results of the photographic programme to date, it is convenient firstly to consider the photographs in relation to the different regions and features of sea-floor topography, and secondly to illustrate various topics of especial interest that have emerged from a study of the photographs. In some instances, colour photographs are used to illustrate various points, since these give a truer representation of the bottom.

REGIONAL CLASSIFICATION

The nearest and most accessible region of the sea floor is that of the continental shelf, where the water depth seldom exceeds 100 fathoms. The coastal part of the shelf has been frequently photographed by divers and so will not be considered further here. It is difficult to generalize about the nature of the bottom on the shelf since there is as much variety here as there is in the geology of the land. Apart from rocky outcrops and beds of seaweed in the shallower water, a lot of the shelf off the coast of Europe consists of sand, shells, gravel, and mud. The presence of abundant molluscs and other large shells and of coarse gravel is typical of shallow-water shelf deposits. Frequently, one finds the sand patterned by ripple marks, the product of the strong tidal streams and currents around the continents.

As we proceed towards the deep ocean, we come to the continental slope which begins quite suddenly, the depth increasing to 2000 fathoms or more in 20 miles. The slopes are often cut with deep canyons carrying the shallow-water sediments out to the deep sea. Apart from these canyons, the slope is a region of deposition of the fine silt and clay material that has been carried out from the coast. Photographs show a smooth featureless bottom suggesting fairly rapid sedimentation.

In deep water, the bottom of the great ocean basins can be divided physiographically into several regions. Apart from seamounts, ocean trenches, and mountain ranges, the bottom is

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more or less completely covered with a blanket of sediment many hundreds of feet thick. Some areas reflect the buried topography in an undulating bottom, and others have an extraordinary flatness associated with sedimentation by turbidity currents. These are currents of water containing sediment in turbulent suspensions that can flow along gentle gradients on the sea floor for many hundreds of miles. At close quarters, however, both the abyssal plains and the undulating bottom are very similar. The ooze is soft enough for extensive reworking by bottom-living organisms which leave tracks, burrows, mounds, and other evidence of their existence. In some cases there are indications of the originator of these features, such as the impression of a five-armed star on the top of many of the small humps, but more often one is left to guess when and how they were made. Occasionally, one is lucky enough to see a sea cucumber or a brittle star crawling along the bottom, or some tube worms or a sponge sticking out of the ooze, but the density of life in abyssal depths is very low. Typical photographs of this region are shown in figures 3, 4, and 12.

The great mid-Atlantic ridge divides the Atlantic Ocean into eastern and western basins. This vast chain of mountains has an obscure origin and much work has been done to elucidate its structure but without any conclusive results. Photography has shown that its rocky peaks are areas of extremely low sedimentation, and have been subject to recent and violent upheaval. Figure 5 shows steep slopes and freshly cleaved rocks resembling the screes found on land. Other photographs have shown basins of sediment covered with patches of shingle-like material that may in fact be colonies of a deep-sea shellfish. On the whole the rocky peaks appear poor in sessile fauna, a fact consistent with the idea of a geologically recent disturbance.

By far the most interesting and varied collection of sea-bottom photographs has been taken on the volcanic seamounts that rise out of the deep basins. In general the greater the depth, the less dense is the faunal population. The attraction of a seamount to the abyssal fauna is doubtless partly related to its geological formation. There are a great many exposed rocks and boulders in varying states of fracture; there are sands and oozes in great variety. These offer to the fauna a variety of footholds and, to fishes, shelter in which to hide from their foes. Possibly nutrients are concentrated in the water in these regions by local upwelling due to obstruction of the water flow and by the solution of minerals from the rocks themselves. Examples are shown of the continuous type of submarine lava flow, of the bedrock, of broken boulders and shingle, and of the current-swept sand with ripple marks. Often it appears that the fauna of one seamount differs from that of another and that where in one place for instance one finds predominantly crinoids, in another there may be sponges. However, this differentiation may only be the result of inadequate sampling techniques and until more pictures are taken it cannot be confirmed. Photographs taken on seamounts are illustrated in figures 6–11 and 13–16.

Photographs were taken of one bank of especial interest off Cape Finisterre. Galicia Bank, which is divided from the continental shelf by a depth of 1500 fathoms, has a structure that may be related more nearly to that of the continent than to that of the ocean floor. Rocks dredged from it are of two distinct types; limestones and a collection of dark metamorphic rocks. The photographs strongly suggest that the limestone is locally derived, whereas the metamorphic rocks are erratic and have possibly been carried by icebergs from the north (figure 17).

SPECIAL PROBLEMS

The geological interpretation of rocks seen in bottom photographs is extremely difficult unless hand specimens can be examined. However, some very interesting features of deep-sea geology have been revealed. In particular, photographs have indicated the distribution and the environment of the rocks. In the Pacific Ocean, millions of tons of potential manganese ore have been found scattered on the deep-sea bed in the form of manganese nodules. The exposed surface of nearly all rocks in deep water slowly acquires a coating of manganese dioxide and this can be used to indicate which way up a piece of rock lay. In figure 5 the white patches on the broken boulders are probably places where a manganese coat is lacking and one can infer from this that they have been disturbed quite recently from the position in which they have lain for many thousands of years. The cauliflower texture seen on the rock on the left of figure 16 is due to a similar manganese crust.

Underwater lava flows have been found photographically in a region where a dredge has been unable to pick up any loose material from the bottom. In figure 6, photographed from the American research vessel *Vema*, the roundness of the rocks is similar to that of the pillow lavas found on continental rocks and believed to have been solidified

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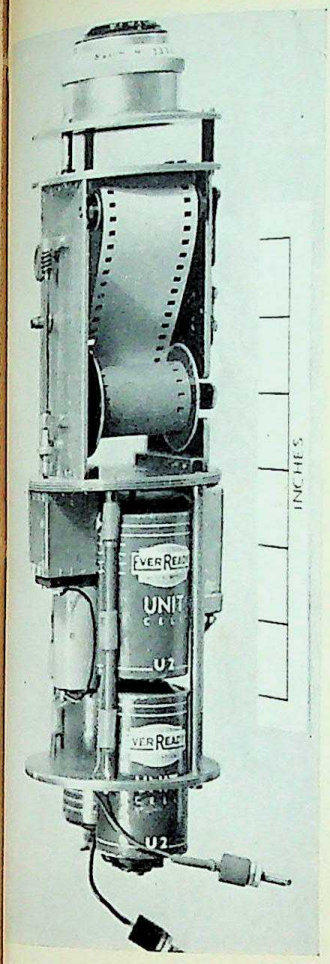

FIGURE 1 (*left*) – *Photographic unit, showing batteries, motor, gear-box, film drive mechanism, and lens. (This model has no shutter.)*

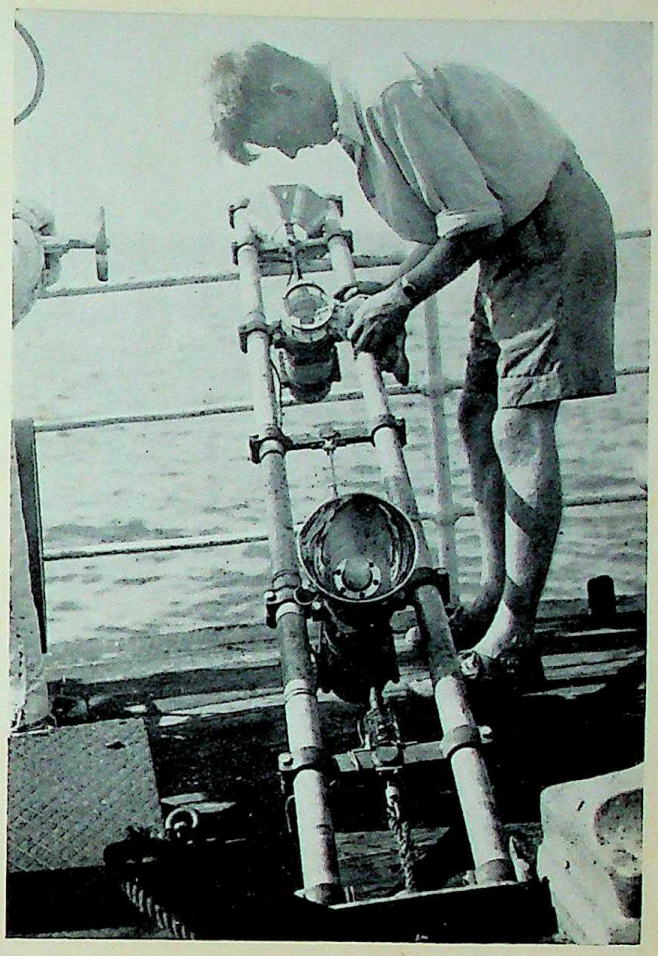

FIGURE 2 (*right*) – *Deep-sea camera in operation. Units are: acoustic transmitter (at the top), photographic unit, flash unit, bottoming switch, trigger weight, and sampler.*

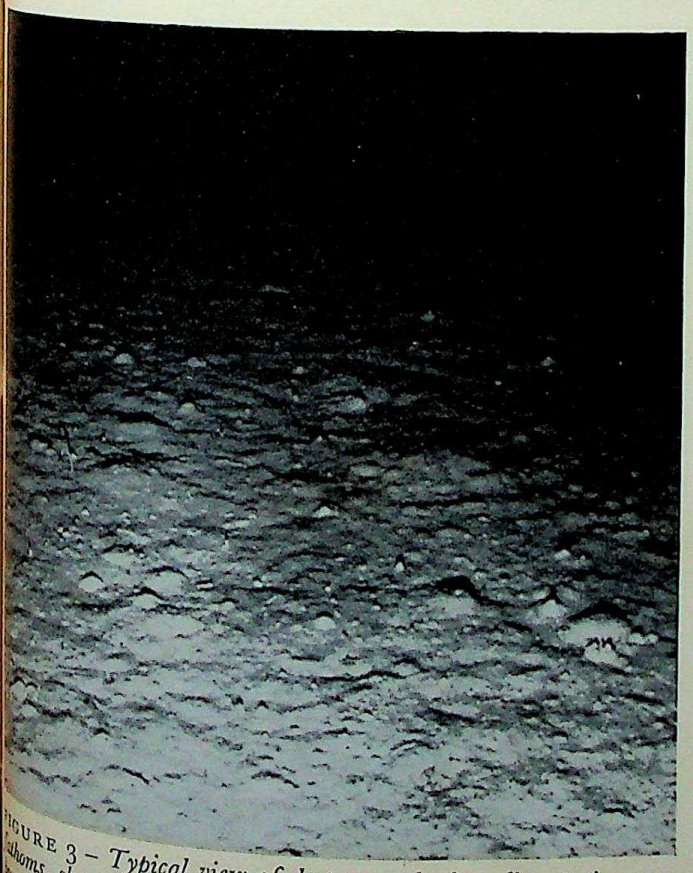

FIGURE 3 – *Typical view of deep-ocean basin sediments in 2550 fathoms, showing the extensive activity of bottom fauna in creating furrows and mounds.*

FIGURE 4 – *A four-inch-wide track in the ooze of a deep basin (2890 fathoms) perhaps made by an animal travelling on the surface and scooping the mud into the central ridge while feeding.*

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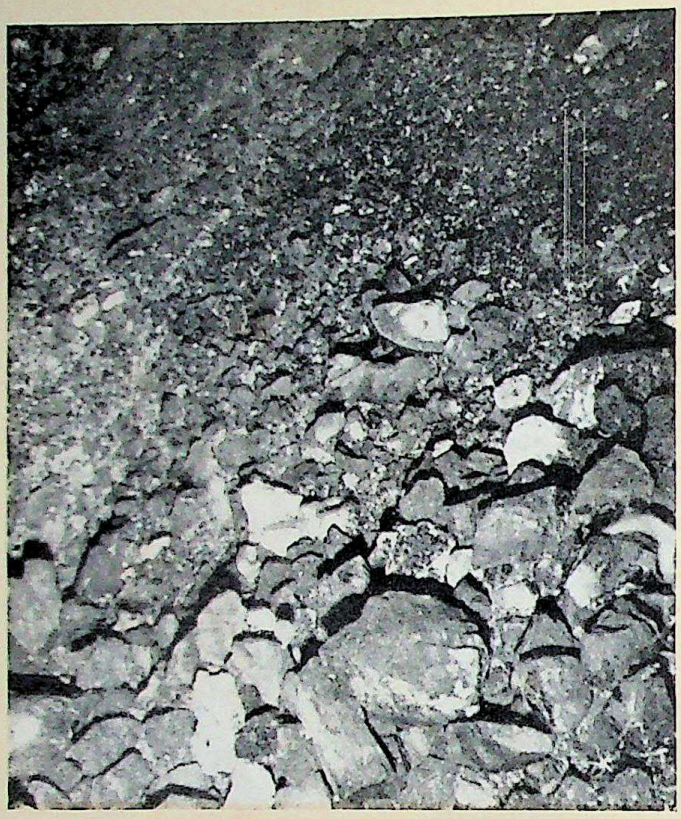

FIGURE 5 – *Scree slopes on a peak on the mid-Atlantic ridge at a depth of* 800 *fathoms, showing absence of sediment and some signs of recent disturbance.*

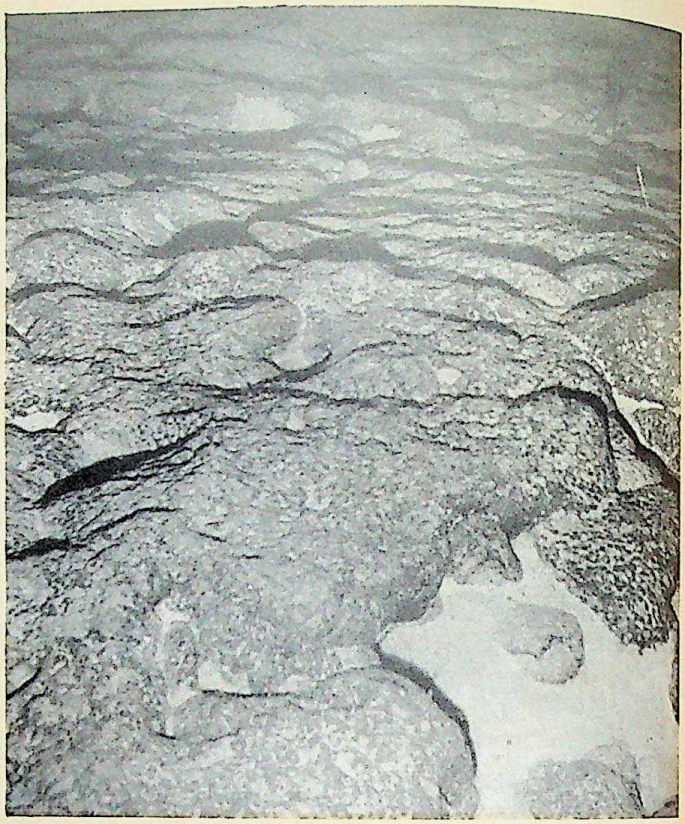

FIGURE 6 – *Oblique view of an underwater lava flow on the side of a volcanic seamount at* 720 *fathoms.*

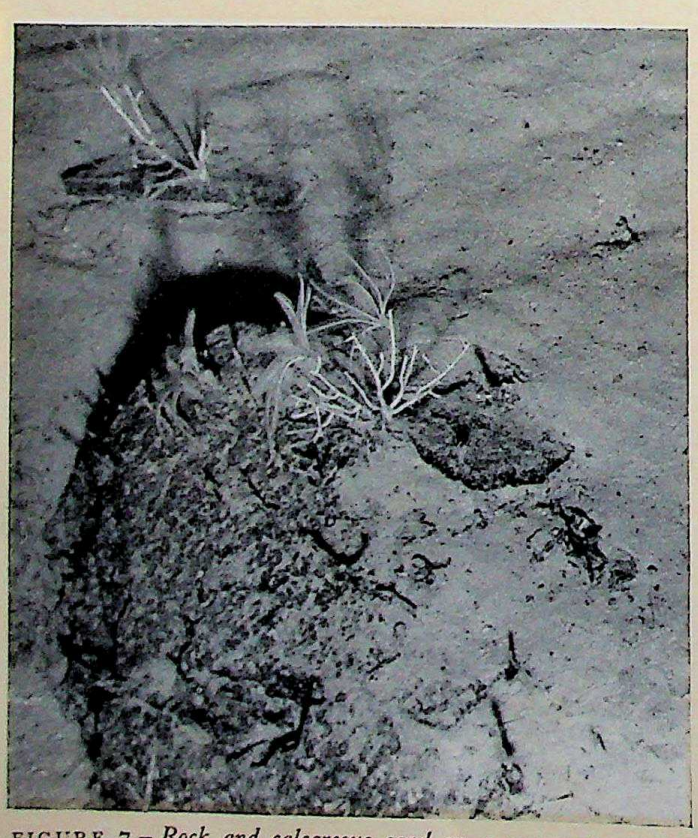

FIGURE 7 – *Rock and calcareous sand on a seamount at* 1580 *fathoms. Feathery comatulid crinoids are seen attached to branching corals.*

FIGURE 8 – *Gorgonians, pennatulids, sponges, corals, and sea urchins on the top of a seamount at* 75 *fathoms, showing the increased faunal population in shallow water.*

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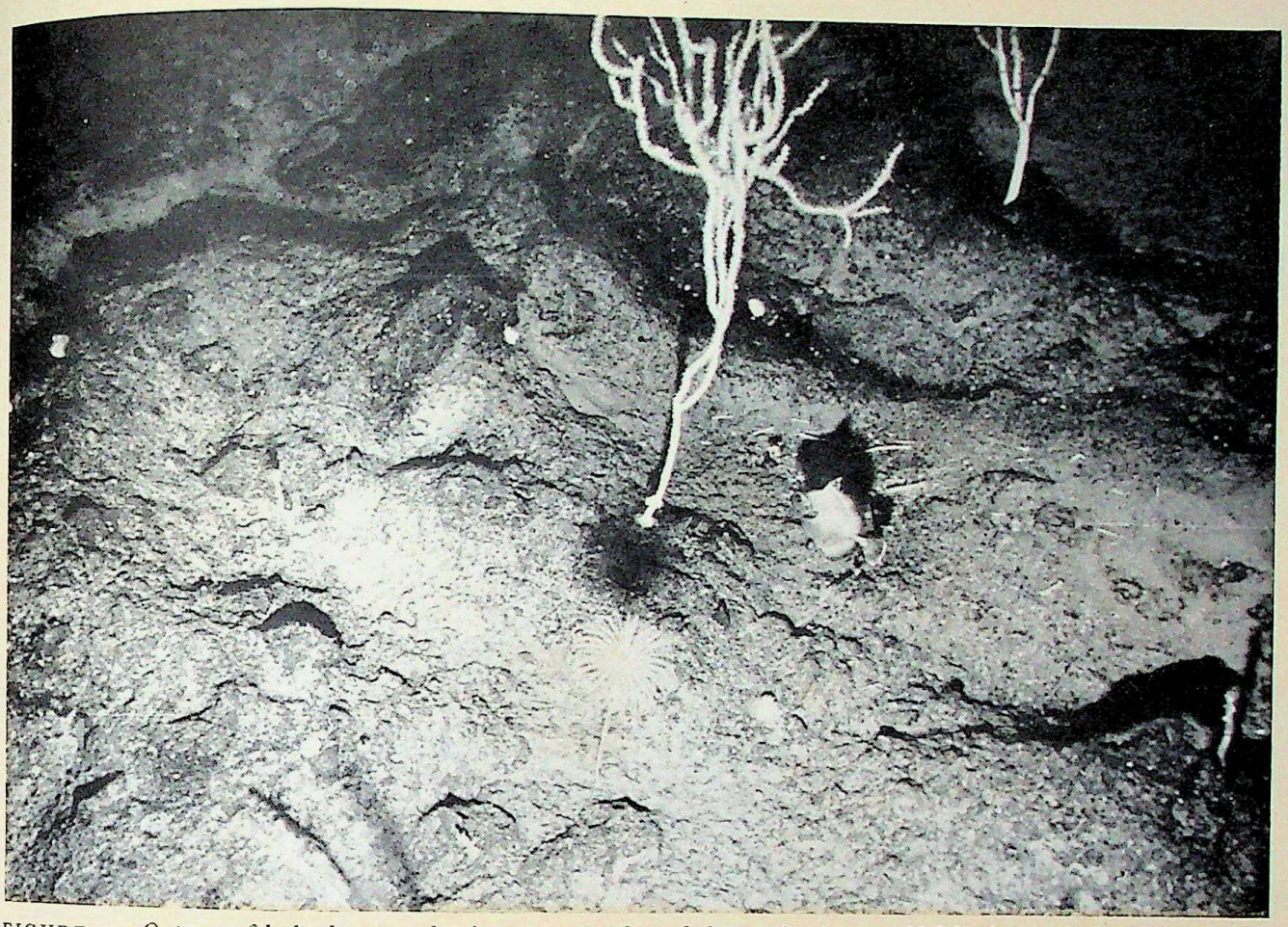

FIGURE 9 – *Outcrop of bedrock on a volcanic seamount at* 800 *fathoms, showing a zeid fish, three varieties of gorgonians, anemones, and some spicular debris deposited by current action. The central gorgonian is more than* 5 *ft high.*

FIGURE 10 – *Ripple marks, scour, and sand-drifts in a calcareous sand on a seamount at* 1710 *fathoms.*

FIGURE 11 – *A rare holothurian* (Peniagone), 8 *inches long, showing feet, branching tentacles around its mouth for feeding, and its 'sail' in a collapsed condition* (*extreme left*). *Depth* 1560 *fathoms.*

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FIGURE 12 – *Soft globigerina ooze on an abyssal plain at 2900 fathoms. A pale-blue sea lily sits on a burrow (12 inches in diameter). Note the radial feeding tracks of a buried animal.*

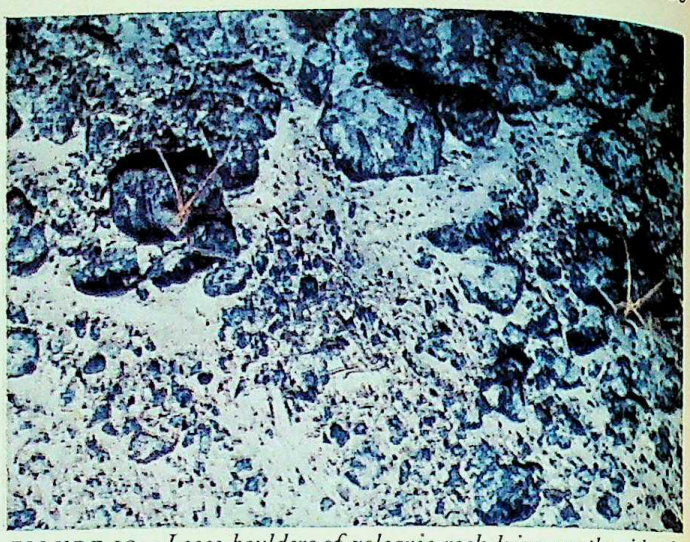

FIGURE 13 – *Loose boulders of volcanic rock lying on the side of a seamount at 1730 fathoms. Two five-armed comatulid crinoids are attached to the rocks and miscellaneous organic debris is scattered between.*

FIGURE 14 – *Boulders and cobbles lying in loose sediment on the side of a seamount in 1810 fathoms. Of special interest is the gravel-size material lying in the lower right-half of the picture which, on close examination, has the appearance of mollusc beds.*

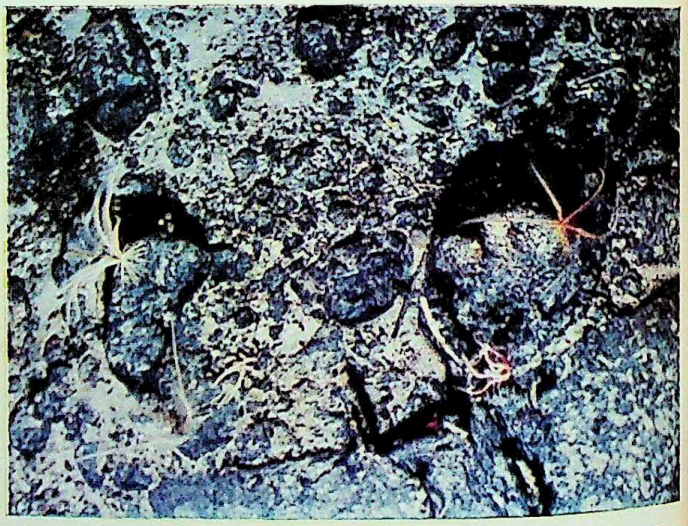

FIGURE 15 – *Five- and ten-armed crinoids attached to boulders on the side of a seamount at 1840 fathoms. A pink brittle star and a red deep-sea prawn (in the shadow of a rock, lower right) can be seen.*

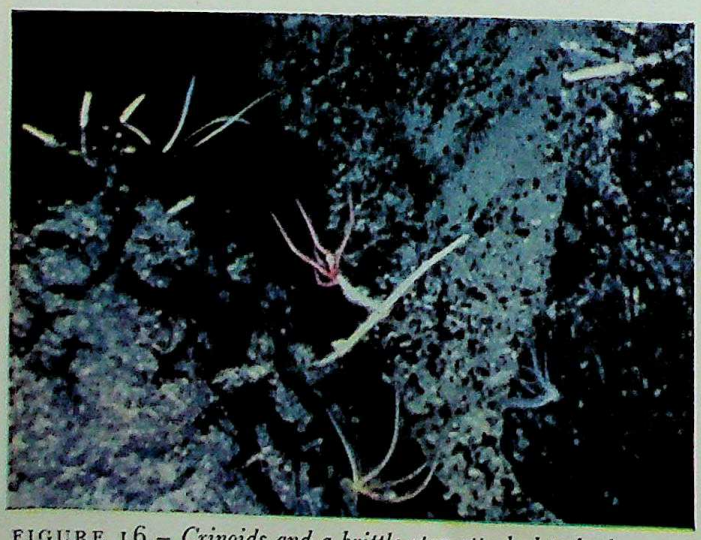

FIGURE 16 – *Crinoids and a brittle star attached to broken coral at 1890 fathoms. The surface of the left-hand rock has the typical 'cauliflower' appearance associated with the growth of a manganese crust.*

FIGURE 17 – *On Galicia Bank at 350 fathoms. The pale rocks (probably limestones) are locally derived, whereas the dark rocks have been carried from elsewhere.*

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under water. Once again the nodular manganese coating is plainly visible.

The ripple-marks found in the deep sea are of great interest to sedimentary geologists. At one time it was thought that the deep sea was a region of very small currents and that the existence of ripple-marks in a sedimentary rock indicated deposition in shallow water. We now have direct evidence of ripple-marks being formed in deep water together with scour and sand drifts around obstacles in the sand. Figure 10 shows these features in globigerina sand at a depth of 1700 fathoms.

Almost every photograph taken in the deep ocean shows evidence of some kind of life existing there. In most cases it is impossible to give a specific name to the animals found, since the systematic classification has been based on detail that is often not visible in a single picture. However, the pictures do show the animals in their normal habitat and in undamaged condition, whereas many of the dredged specimens have suffered damage in collecting, and distortion in the resultant pickling and storing in formalin. Figure 11 shows an unusual holothurian that was previously known only from extensively damaged specimens collected by H.M.S. *Challenger* in 1875.

One of the most fascinating puzzles posed by the pictures is the identification of the tracks and burrows found over the wide areas of the soft bottom. One must appreciate that with the sediment accumulating at the slow rate of only a centimetre or less in a thousand years, a track once made will be visible for a very long time. Thus the density of tracks reflects the activity of several thousand years. Some of the tracks are made by animals on the surface and some by animals beneath it. Figure 4 shows the broadest tracks found (about four inches across) and is representative of many such tracks found beneath the Atlantic. A similar track, but with much more pronounced transverse marks was photographed by Zenkevitch from the Russian research ship *Vityaz*, in the Pacific. Although the central part of the track is raised, it must have been formed by an animal on the surface because of the regularity of marking. A possible interpretation is that the track was made by a mud-feeding animal which scoops the mud into its mouth with some form of arms or tentacles, producing transverse marks and a ridge of ooze, the central depression being made by a trailing tail. Possible animals to fit this theory are decapod crustaceans and holothurians of the type shown in figure 11.

Other interesting tracks are the sinuous and the spiral forms. These appear to have been made by worms burrowing just below the surface and stop suddenly when the worm burrows downwards. The shapes of these tracks provide interesting evidence of the way in which an animal can search an area most economically and systematically.

Many other interesting problems arise out of these photographs concerning the relationship between fauna and their environment. Photography will doubtless be used more and more in the future to study deep-sea marine ecology.

FUTURE USE OF UNDERWATER PHOTOGRAPHY

It is clear from the above discussion that deep-sea photography has its place in any investigation that includes the sea bottom. A photograph is second-best to direct observation, but until bathyscaphes become more common, direct observation is not possible. It may be advantageous, in sampling the bottom, to attach a camera to the corer or dredge to estimate the sampling technique more efficiently. Certainly, if it becomes a practicable proposition to drill into the solid rock of the sea bed, photographic control would be most desirable.

The deep-sea camera has been used as a tool in a number of ways other than those described. Fish, squid, and the deep scattering layer have been photographed in midwater using suitable triggering devices and the camera has been incorporated as the recording method for the measurement of currents on the sea floor. Doubtless many other uses will be found in the future.

ACKNOWLEDGMENTS

I am grateful to the Director of the Lamont Geological Observatory, New York, for permission to publish the photographs shown in figures 6 and 8. Figure 2 is published by permission of the British Petroleum Company.

REFERENCES

[1] Ewing, M., Vine, A., and Worzel, J. L. *J. opt. Soc. Amer.*, 36, 307, 1946.
[2] Laughton, A. S. *Deep-Sea Res.*, 4, 120, 1957.

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The Darbys of Coalbrookdale

A. RAISTRICK

This year is the 250th anniversary of the first successful smelting of iron with coke, by Abraham Darby, an event of outstanding importance in the history of technology. Coalbrookdale, the scene of this achievement, has since remained an important centre of the iron industry. There the cylinders of many of the early steam engines were cast, Abraham Darby III built the world's first iron bridge, the first iron rails were made, and the first high-pressure steam engine was constructed for Trevithick. Later, Coalbrookdale played an important part in the development of cast iron as a constructional material for a wide variety of purposes.

The introduction of the blast furnace from the Continent at or just before the beginning of the sixteenth century marked the opening of a new phase in the history of ironmaking in Britain, for not only was the plant more elaborate but the process of obtaining malleable iron was different. The old bloomery process [1] gave directly an iron of the quality required for forging. It worked at a temperature too low for fusion, and in consequence harmful impurities such as sulphur and phosphorus did not enter the iron as they did when blast furnaces were used. Pig iron made in blast furnaces had a high carbon content, and this had to be reduced, in a separate operation, before the iron was suitable for most of its uses. This reduction was effected in fineries, in which the cast iron was melted and stirred: it was then consolidated by hammering, being reheated at intervals in the chafery. These additional operations called for extra labour and fuel, but in the long run these disadvantages were outweighed by the greater productivity of the blast furnace. Productivity became a major factor as the demand for iron increased, but the primary reason for the adoption of the blast furnace in Britain seems to have been military. Many charcoal-burning blast furnaces were established: by 1600 nearly a hundred were in operation, more than sixty of them in the Weald of Sussex area, where gun founding was the mainstay of the industry [2].

The seventeenth century saw the exploitation of the iron ores in the Forest of Dean and of coalfield ores, with a corresponding migration of ironmaking into south Yorkshire and the Severn valley, and a concentration of forges and smithies to manufacture iron goods, in the Midlands [3]. The coalfield ores contained a substantial amount of phosphorus (0·15–0·42 per cent) and so made a pig iron that was brittle when cold ('cold-short'), but the Forest of Dean ores were almost free of phosphorus (0·07 per cent). When pig iron from these two sources was mixed in the forge a very good wrought iron resulted. This circumstance, with the advantage of easy transport along the Stour and Severn, eventually established the Midlands and Welsh Borders as great iron-making and iron-using areas, with Bristol as the natural market and port for their products.

This concentration of furnaces and forges in the Severn area created problems, however. The competition for charcoal became severe, and in consequence its price increased threefold. Attempts to make working more economical by increasing the size of the blast furnace were frustrated by the fact that charcoal has too little mechanical strength to support a column of ore more than about 25 ft in height: when the charcoal was crushed by the load on it, the blast was choked. A cheaper and stronger fuel was therefore a prime necessity for the advance of the industry, and it is not surprising that many experiments were made to use coal in place of charcoal in blast furnaces. Dud Dudley claimed to have achieved success in 1619, but his claims are not acceptable [4]. Many others experimented, and some, such as Grandison, Sturtevant, Addison, and Rovenson, obtained patents; none, however, achieved real success. One great difficulty was the presence of sulphur in the coal, since this adversely affects the metal. As a result, attention was directed to the possibility of using coke, for the process of coking eliminates the sulphur. This was already known to maltsters, who, for quite other reasons, had to avoid contaminating their product with sulphur. Moreover, coke was beginning to be used at the start of the eighteenth century in copper-smelting and lead-refining, so that it was not an altogether strange product in the metal industry. Coke used in malt kilns near Derby was made by firing open heaps of

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coal covered with dust: this gave a yield of approximately 33 per cent.

Such, in very brief outline, was the background to the successful introduction of iron-smelting with coke by Abraham Darby (1678–1717) in 1709. By both birth and early training he was well qualified for this achievement. He was born near Dudley, Worcestershire; his father and grandfather were locksmiths, and he thus had many opportunities of observing the smith's use of iron. As a young man he was apprenticed to a maltmill maker, and so must have learned of the use of coke by maltsters and its methods of preparation. In 1699 he set up as a maltmill maker in Bristol, his choice of this city doubtless being decided in part by the fact that the Quaker community, to which he belonged, was strongly represented there. Bristol was a centre for copper and lead smelting, and in 1702 he formed the Bristol Brass Wire Company, with other Quakers as his partners. One of them was Nehemiah Champion, whose family was for several generations intimately connected with the brass and copper industry and with the iron trade. In copper-smelting a charge of two-thirds coke and one-third coal was then being used in a furnace resembling the steel cementation furnace, and Darby must have become very familiar with this practice before he turned his attention to iron.

With his brass-making enterprise well established at Bristol, Darby in 1708 formed the Bristol Iron Company, where he put into operation a patent he had been granted in 1707 for casting iron 'bellied pots' (or cauldrons) in dry sand. He was soon seeking a place to make his own iron, and eventually leased the Old Furnace in Coalbrookdale: this stood near the Severn in an area where coal and ironstone had been mined for many years. One of the local coals, from the Clod seam, was a good coking coal, low in sulphur. Darby probably knew of its properties from his earlier experience, and it was doubtless this that led to his choosing this particular coal for his first experiments in smelting iron. The furnace was leased from September 1708, and by January 1709 it had been repaired and blown in. By 25th January 1709 'a parsell of new pigs 4 tons 5 cwt 2 qr 0 lbs at £6. 10. 0. per ton' was sent to Bristol. This was a major landmark in the history of iron-making, for it was the first commercial iron to be smelted with coke, an achievement which marked the birth of modern iron technology.

Darby used the iron from his furnace to cast pots and other hollow ware. One very important feature of his work was the thinness of the castings, which allowed his cast-iron pots to compete successfully with the heavier brassware then widely used. Coke gave a higher hearth temperature in the furnace than was reached with charcoal and in consequence more silicon in the pig iron; this factor, together with the fact that the phosphorus content of the ore was high, resulted in a very liquid melt, and consequently relatively low risk of blowholes in the castings.

At that time a charcoal furnace was usually blown for 25–30 weeks in the year, the rest of the year being needed to accumulate sufficient charcoal: one furnace could absorb the available charcoal from a considerable area. By contrast, a coke furnace could be blown for 48 weeks in the year, and a coalfield could support a number of furnaces without any interruption of fuel supply. The output of a charcoal furnace was about 15 tons of iron a week, and although an early coke furnace would make only about 5 tons a week this was soon improved on; moreover, the better fuel supply and the longer blast allowed a number of coke furnaces to work together and provide whatever increased output was desired.

The first Abraham Darby died in 1717, and the works were continued by his son-in-law Richard Ford (1689–1745), who had been employed by Abraham Darby as his clerk and assistant in the works. In 1728 Abraham Darby II (1711–63) was taken into the works and ten years later became a partner in the business. Of the children of his second marriage two sons, Samuel and Abraham III (1750–89), and two daughters, Mary and Sarah, all took some part in the business. Under Ford the casting of engine cylinders, pumps, and pipework was begun at the Old Furnace, and he continued casting pots and other articles at the New Furnace, built in 1715. Cast-iron cylinders were so much cheaper than brass, and easier to make in large sizes, that they soon became the only ones used in the atmospheric (steam) engine, of which the first satisfactory example was built by Newcomen at Dudley Castle, Worcestershire, in 1712. By 1758 the Company had cast more than 100 cylinders for Newcomen engines, including some of very large size. For example, one cast for an engine installed at the Walker Colliery, Newcastle upon Tyne, had a diameter of 6 ft and a length of 10½ ft: it weighed 6½ tons. The immense technological significance of the Newcomen engine needs no emphasis: the beam-engine conquered flood water in mines and revitalized the mining industry.

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Attempts to improve the furnace performance were dominated by the need for a stronger blast, and one that would be available throughout the year. The water-wheel then used was not satisfactory, as it could not be worked when the stream was low. In 1733 horse-driven pumps were used to return for re-use water that had already turned the water-wheel that worked the bellows. In 1742 Abraham Darby II applied a steam engine to this task and secured a great improvement in production.

The market for cast-iron goods was not very extensive, and the pig iron produced in the coke furnace was difficult to refine into good wrought iron because of its high phosphorus content; consequently the sale of pig iron outside Coalbrookdale was not very important. As late as 1760 only seventeen coke-burning blast furnaces were in operation in Britain. From 1748 onwards, however, Abraham Darby II gave his attention to the problem of producing from the blast furnace an iron suitable for the forges. He ultimately solved it chiefly by selecting the most suitable ores available, those known locally as Black, Ball, and Penny ironstones, containing about 0·1 per cent phosphorus. In 1753 he built two furnaces at Horsehay and two more at Ketley: these four furnaces each had an output of 15 tons a week, raised in the next ten years to 25 tons each. A substantial part of the pig iron so produced was sold to the Midland ironmasters, such as Knight and Foley, for conversion to bar iron; only then was the industrial success of coke smelting established. Coke-fired furnaces were built by Wilkinson in Staffordshire; by the ironmasters of South Wales, Yorkshire, and Scotland; and by the end of the century by those of France, Silesia, and Prussia. Abraham Darby I was the pioneer of coke-smelted iron for the foundry; Abraham Darby II was the originator of coke-smelted iron for the forge and rolling mill.

The Dale Company, as it was then known, developed its own forges and produced bars and sections both for use in its own manufactures and for sale, and it built a large mill to make boiler plates. By 1785 four more furnaces had been built and there were sixteen steam engines serving the works and furnaces, nine forges, rolling mills, and furnaces for the casting shops. The capital of the Company was more than £100 000 [7].

By the provision of cheap cylinders of large diameter for steam engines Coalbrookdale made a major contribution to the development of the mining of both coal and metals, and this interest continued until the present century. Two immediate problems created by the cylinder-casting business were the handling and transport of massive castings of iron about the works and to the wharf, and the making of a large melt, weighing several tons, for a single casting. The first was met by an extensive system of tram roads, some twenty miles in all, between pits and furnaces and about the works; this was established in 1748 and improved in 1767 by the substitution of the world's first cast-iron rails for old wooden ones.

A widely known monument to the works' capacity to cast and handle large masses of iron is the famous Iron Bridge across the Severn, half a mile below Coalbrookdale, the first iron bridge in the world (figure 2). This was designed, cast, and erected in 1779 by Abraham Darby III and was the forerunner of a long series of bridges, the making of which was later transferred to the Horsehay Works; this production has been continued and extended by the present Horsehay Company since 1886. For the Iron Bridge castings, the Old Furnace in Coalbrookdale was reconstructed and in this form it is still in the works (figure 3), and was displayed by the Coalbrookdale Company (Allied Ironfounders Ltd) to mark the 250th year of their existence. The use of structural cast iron had developed both in iron-framed buildings by 1796 [8] and in a variety of architectural castings, columns, railings, and smaller items.

The versatility of the Company and their readiness to experiment encouraged engineers to come to them with unusual demands. In 1756, 1759, and again in 1763 James Brindley was in the works supervising the making and testing of a steam engine and of a new type of boiler of his own invention. A local engineer, Joseph Hornblower, for many years from 1735 onwards, had castings for Cornish mine engines made at Coalbrookdale. The family connection was maintained for at least three generations: in 1781, for example, Jonathan Hornblower sent his son to discuss his idea for a compound engine, which was successfully built and used in the works, and was eventually brought into general production. Adam Heslop, brought up in the works, invented an engine with two cylinders, one 'hot' or operative, using the steam under pressure, the second one 'cold', taking the used steam and condensing it, so acting as an atmospheric engine. It was in fact one of the first compound steam engines and was granted a patent in 1790. The action was smooth, and was preferred to the Boulton and Watt for use on many of the Coalbrookdale mines and plant.

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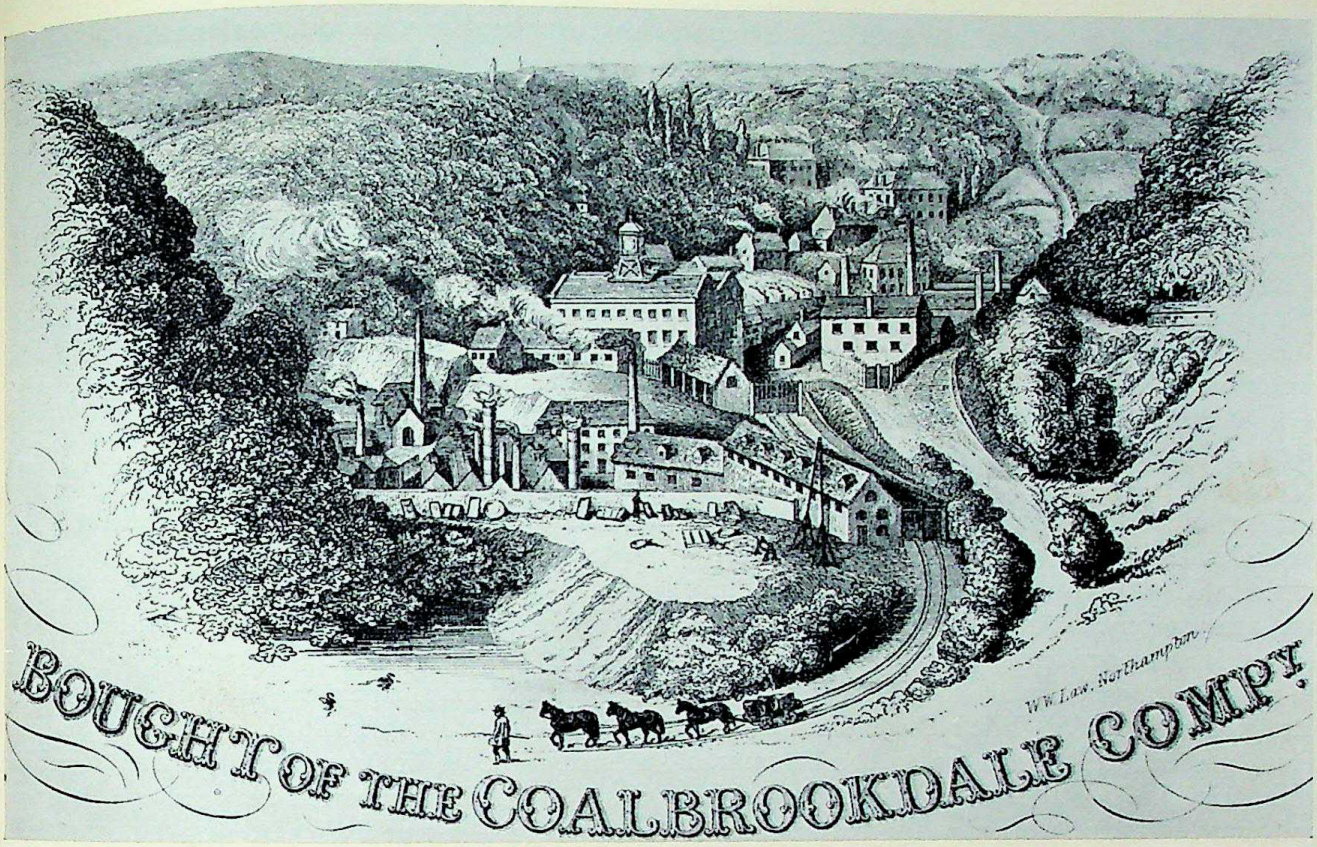

FIGURE 1 – *Engraved billhead showing comprehensive view of Coalbrookdale works,* 1843.

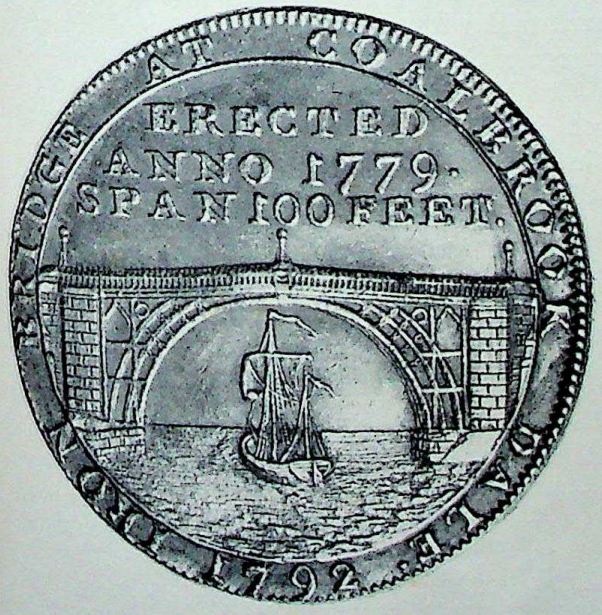

FIGURE 2 – *Trade token of* 1792, *showing the Iron Bridge at Coalbrookdale.* (× $2\frac{1}{2}$)

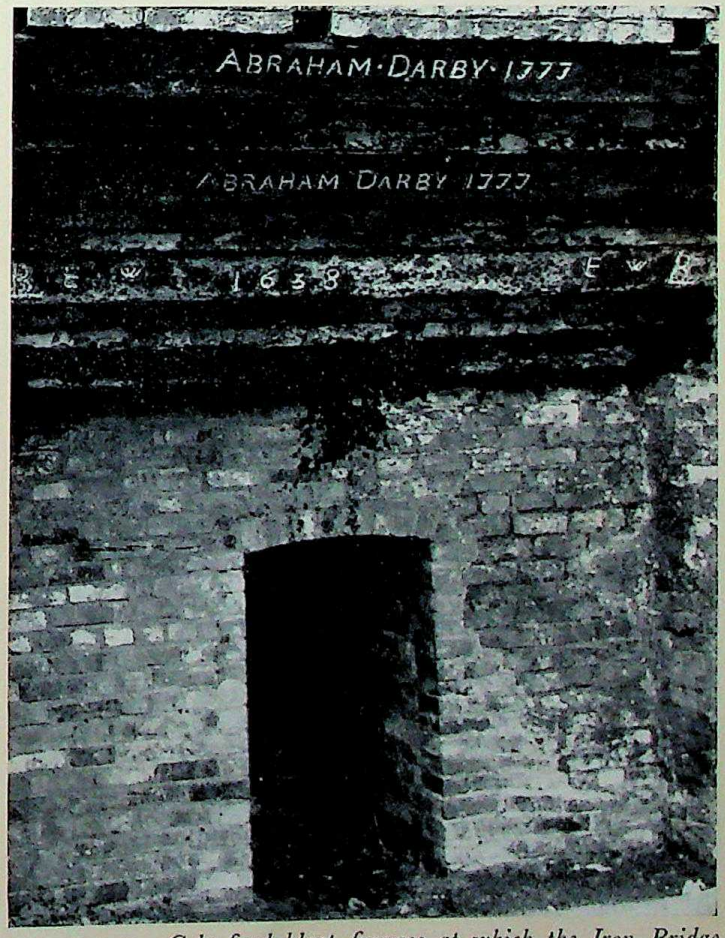

FIGURE 3 – *Coke-fired blast furnace at which the Iron Bridge castings were made.*

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Later, Sadler came to Coalbrookdale to have his ideas for an improved tandem steam engine translated into practice. Several engines were made to his plan and, like Heslop's, were used in the mines; later Sadler had them produced for the naval dockyards at Plymouth.

In 1790, the Company began to make boiler plates of large size by rolling; these in due course made possible the construction of boilers working at high pressures. In 1796 Richard Trevithick, who, like his father, had had experience of Coalbrookdale engines in Cornwall, visited the works. In 1802 he came again, this time to have a high-pressure boiler made and tested, and his first rail locomotive built. Coalbrookdale already had experience in this field, for as early as 1787 William Reynolds had made experiments in steam locomotion within the works, but a fatal accident to a workman had caused them to be abandoned. The Trevithick locomotive, the first in the world to run on rails, is almost certainly represented in a well-known drawing of a 'Tram Engine' which was wrongly attributed by Mason to the Penydaren locomotive [10]. A boiler and pumping engine built for Trevithick worked with great success at 145 lb/in^2 pressure—a pressure far beyond any previously attained at that date, when engines still normally used steam at little above atmospheric pressure. On 22nd August 1802 Trevithick wrote to his friend David Giddy, later President of the Royal Society, 'The Dale Co. have begun a carriage at their own cost for the realroads and is forceing it with all expedition' [9]. Several locomotives were built during the nineteenth century for use about the works. From these early experiments stemmed the general use of high-pressure steam and the modern steam locomotive.

In the first decade of the nineteenth century a process of rationalization resulted in the plant and operations being divided into several well-defined units. Output from the forges had already reached 1200 tons a month—very high by the standards of the day—and the employees numbered over 2000.

During these years of reorganization there had been a general depression in the iron trade, and in 1816 the works at Ketley were given up. However, by 1830 there was a recovery, and the Company started on another phase of development. Under the guidance of Francis Darby (1783–1850), the son of Abraham Darby III, there was a great development of artistic and architectural castings and of the manufacture of gates and railings. In 1851 the Company exhibited in the Great Exhibition and received a Council Medal. At that time it had between three and four thousand work-people, and output was 2000 tons a week: it was the largest ironworks in the world (figure 1).

The nineteenth century was remarkable for the development of cast iron as a constructional material, in which use the Company had set a striking pioneer example with the Iron Bridge, and this is fully illustrated in its products. The amazing variety of articles offered in cast iron—the catalogues listed thousands of different articles—is today difficult to appreciate. There seemed to be no limit to what cast iron could be made to do: its use varied between the finest of art castings—filigree fruit plates or the reproduction of da Vinci's 'Last Supper'—and such massive work as the Hyde Park Gates and the Albert Edward railway bridge over the Severn between Coalbrookdale and Buildwas. Solid-fuel appliances were a notable feature of production, and manufacture of these has continued up to the present day.

From 1827 Francis Darby shared the management of the various concerns with his brother Richard and with Abraham IV and Alfred, the grandsons of Samuel Darby. Abraham IV retired from Coalbrookdale in 1849 to take an active interest in the Ebbw Vale steelworks. Francis died in 1850 and Alfred in 1851, and thus the long line of Darby managers came to an end. Alfred's son, Alfred II (1850–1925), however, became a director of the Coalbrookdale Company and was the last Darby to be connected in any way with the works. As a family, their contribution to the iron industry was remarkable.

REFERENCES

[1] SCHUBERT, H. R. 'History of the British Iron and Steel Industry'. Routledge and Kegan Paul, London. 1957.

[2] STRAKER, E. 'Wealden Iron'. Bell, London. 1931.

[3] JOHNSON, B. J. C. *Econ. Hist. Rev.*, 2nd Ser., IV, 1951–52.

[4] MOTT, R. A. 'Dudley and the Early Coal-Iron Industry'. *Trans. Newcomen Soc.*, **15**, 17, 1934–35.

[5] HOUGHTON, J. 'Husbandry and Trade Improved'. London. 1727.

[6] MOTT, R. A. *Gas World*, **50**, 7, 1957.

[7] Letter from Richard Reynolds to Lord Gower, 28th March 1785, quoted in RAISTRICK, A. 'Dynasty of Ironfounders. The Darbys and Coalbrookdale', p. 97. Longmans Green, London. 1953.

[8] HOBBS, J. L. *Shropshire Mag.*, No. 3, pp. 43–44, 1950, and letter Morley Tonkins, 6th September 1950, quoted in RAISTRICK, A., *loc. cit.*

[9] RAISTRICK, A. *loc. cit.*, pp. 161–68, 1953.

[10] FORWARD, E. A. *Engineer*, **193**, 266, 1952.

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Spectrophotometric technique for studies of respiratory enzymes in living material

H. LUNDEGÅRDH

The enzymes that are involved in cell respiration have, in general, colours that change during oxidation and reduction. They can therefore be studied in the living cell by absorption spectrophotometry. It has been necessary to develop special instruments for these investigations, and this article describes the instruments and some of the results achieved with them.

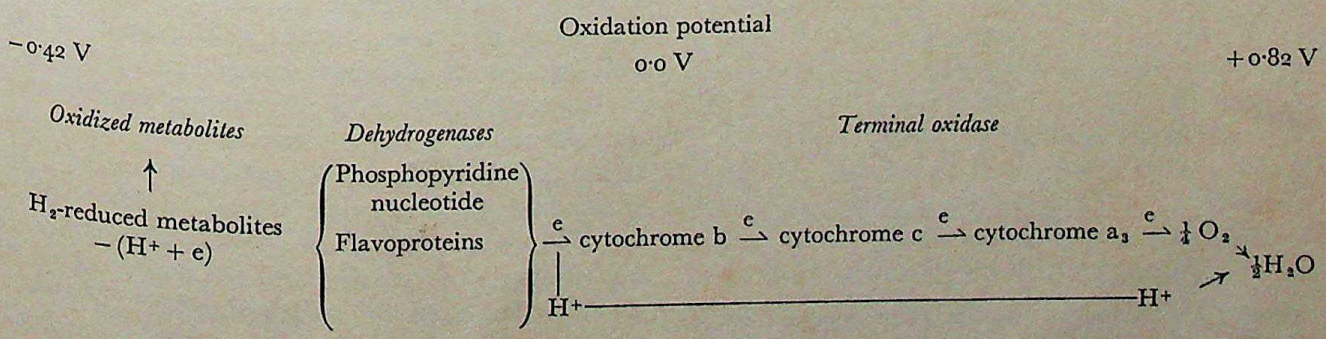
The spectrophotometric technique developed during the last decade has been greatly influenced by studies of respiratory enzymes. In addition to the universal key position of respiratory enzymes in cell metabolism, an obvious reason for selecting them for experimental study is the fact that most of them are pigments which change colour on reduction or oxidation. Spectrophotometry offers the possibility of studying their operation in actually living cells and tissues.

The respiratory chain, a scheme of which is given below, is composed of dehydrogenases, which remove hydrogen from metabolites, and oxidizing enzymes, which, through a series of electron transfers, perform the end oxidation. The large amount of energy developed in the total process is trapped in high-energy phosphate at a number of points in the chain, and only a little disappears as heat.

Each enzyme in the respiratory chain is reduced by one compound and oxidized by another [2], and the corresponding transference of electrons may be followed by observation of spectral changes. The oxidized cytochromes show colours from greenish (cytochrome a_3) through light red (cytochrome c) to deeper red (cytochrome b) and are characterized by sharp absorption bands, the γ-bands or Soret bands, in the blue and blue-violet (see table I) and have only broad indistinct bands in the green and red. During reduction the γ-bands move 10–20 mμ towards longer wavelengths, and new bands (α- and β-bands) appear in the green (cytochromes of c- and b-type) or the red (cytochromes of a-type). Only cytochrome c has been isolated in a pure state, but the cytochromes b and $a+a_3$ also yield comparatively good preparations, which make possible measurements of molar extinction, and of the shape and position of the absorption bands.

Of the dehydrogenases, the coenzymes I and II (di- and tri-phosphopyridine nucleotide) are colourless, but a characteristic ultra-violet band at 340 mμ appears upon reduction. The flavoproteins are colourless in the reduced state but turn more or less yellowish on oxidation, owing to the appearance of a broad band at about 450–470 mμ and a second band in the near ultra-violet.

Because the respiratory pigments are present as individual chemical compounds in the living protoplasm, it is theoretically possible to perform an optical resolution of the total system and to follow the oxidation and reduction of the single enzymes, provided that the true absorption curves of these are known. Modern spectrophotometric methods are here distinctly superior to visual spectroscopy.



Scheme of the respiratory chain of enzymes

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TABLE I

Principal absorption bands of enzymes in the respiratory chain. The molar extinction values (mol^{-1} l^{-1} cm^{-1}) vary between ca. 6×10^3 and ca. 3×10^4. Wavelength values in mμ.

	α-bands		β-bands		γ-bands	
	Oxidized	Reduced	Oxidized	Reduced	Oxidized	Reduced
Cytochrome a_3	None	598	None	None	420	444
Cytochrome a	None	604	None	None	—	452
Cytochrome b	Indistinct[1]	562–564	Indistinct	530	416	430
Cytochrome c	Indistinct	550	Indistinct	520	406	416
Cytochrome c_1	Indistinct	554	Indistinct	522	408	418
	Oxidized		Reduced			
Flavoprotein	450–470		None			
Phosphopyridine-nucleotide ..	None		340			

[1] 'Indistinct' means a broad elevation of the spectrum, the height and shape of which are important in the calculation of the difference spectrum. The broad indistinct α-β-band of oxidized cytochrome c is nearly as high as the β-band of the reduced enzyme (see figure 1).

The instruments mentioned in this article were constructed primarily for a detailed analysis of the enzyme system which carries on aerobic respiration in higher plants and yeast. The respiratory systems in micro-organisms and in plant and animal cells are built along similar lines, but there are differences of detail. The new technique has shown that cytochromes c, c_1, b, a_3 (cytochrome oxidase), and a, all known to exist in animal cells, also participate in the respiration of wheat roots. Plants invariably contain quantities of another haemin enzyme, peroxidase, which shows certain additional oxidizing qualities. Because the technique permits accurate measurements of the extinction at exactly reproducible wavelengths, it has been possible to observe the operation of the individual enzymes in living cells and tissues, as well as in homogenates and in particulate fractions of the protoplasm.

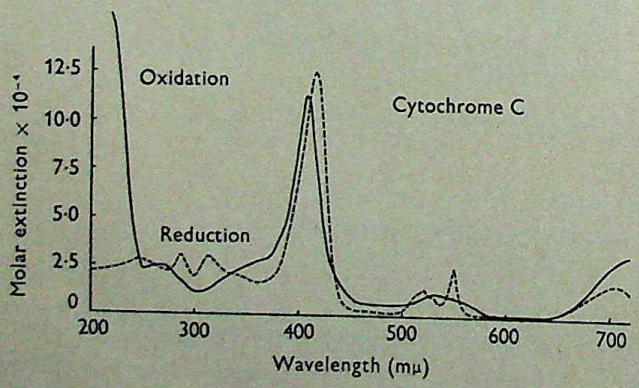

FIGURE 1 – *Absorption spectrum of oxidized and reduced cytochrome c, recorded in intervals of* 1 mμ *with the instrument shown in figure* 3.

These studies of the kinetics of the steady states reveal characteristic differences in the patterns of reduction and reoxidation of the single enzymes which are difficult to explain in terms of free reactants. The co-operating enzymes apparently react as multi-molecular groups which are linked together in definite patterns. The respiratory unit may be looked upon as one of the fundamental building stones of living protoplasm. According to scattered reports in the literature, a number of accessory substances or factors serve as junctions or switchboards for controlling the stream of electrons through the system. Some of the enzymes and factors are sensitive to specific inhibitors, as a consequence of which certain lines of electron transference may be switched off while others remain active. These studies reveal interesting properties of the different enzymes, such as the

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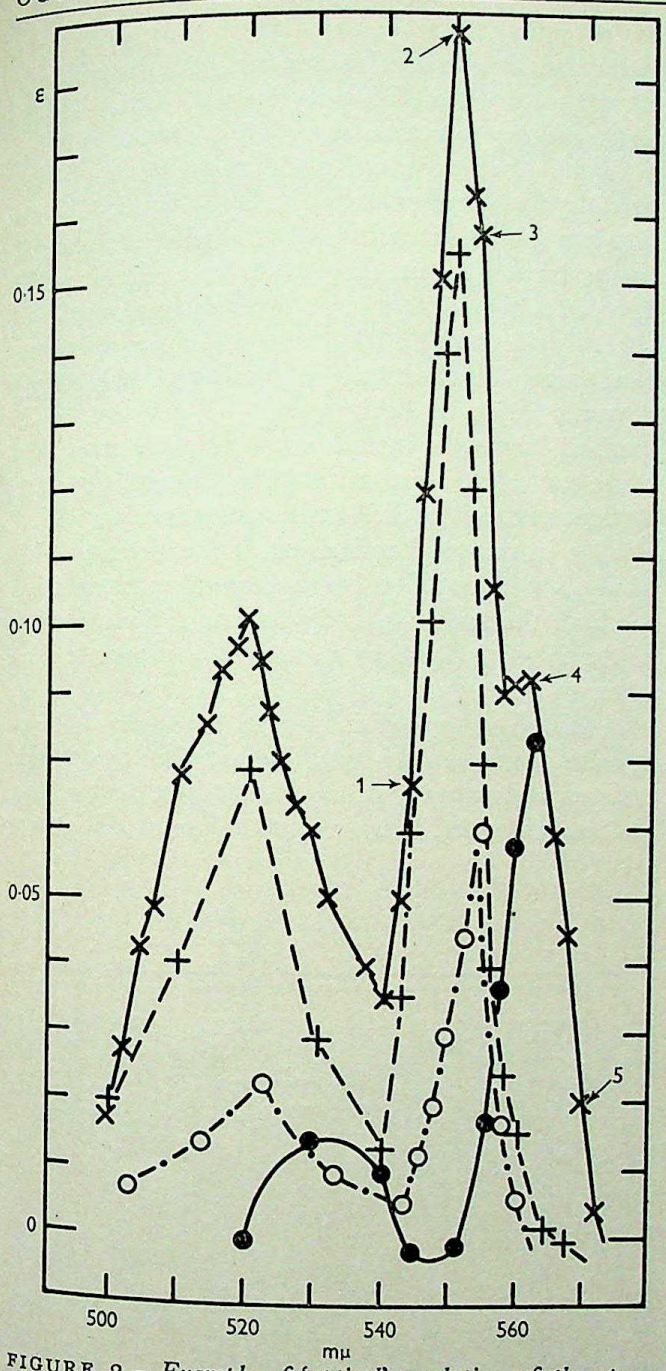

FIGURE 2 – *Example of 'optical' resolution of the spectrum.* x——x, *observed spectrum of a* 15 *per cent suspension of washed yeast gassed with* N_2 *(extinction of reduced yeast minus extinction of oxidized yeast).* +------+, *spectrum of cytochrome c, calculated from the difference* 2–1. ●——●, *spectrum of cytochrome b, calculated from* 4–5. o-·-·-·-o, *spectrum of cytochrome* c_1, *calculated from the difference at* 554 mμ (3) *between the observed spectrum and the calculated spectrum of cytochrome c.*

fact that, of the closely allied cytochromes a_3 and a, only the former acts as an oxidase, and the fact that cytochrome b in plants may act as a b-shunt to oxygen if a_3 is inhibited. Considerable differences in function also exist between the twin enzymes c and c_1 and the frequently co-existing members of the cytochrome b family.

Recording spectrophotometers of high sensitivity facilitate synchronous observations of the activity of the respiratory enzymes and of specific physiological processes, such as the accumulation of salts in plant cells. This last process is one of the fundamentals of the mineral nutrition of plants, and is to some extent also responsible for the turgescence of parenchymas. In its electronic activity the respiratory unit acts as a miniature electric machine, and its activity is in fact related to the concentration of electrolytes in the surroundings, that is, to the conductivity in the external circuit. This non-specific salt effect can be demonstrated by direct spectrophotometric observation of changes in the steady states of the cytochromes when the tissue is supplied with salts. Only plants turn this general effect into an active salt pump. The spectrophotometric observations show a participation of both cytochrome oxidase and cytochrome b in the salt effect. Cytochrome b and, in general, enzymes of the protohaematin type, are more dominant in plants than in animal tissues.

TECHNIQUES

Visual spectroscopy served excellently during the pioneer work of MacMunn and Keilin on cytochromes [1], but the use of a simple spectroscope is of necessity restricted mainly to a statement of the position of visible bands. The spectroscopist is frequently confused by spectra of mixtures of pigments, because the combination of adjacent bands of two separate compounds may result in a misleading shift in the position of the peaks. Only exact measurements of the bands in terms of molar extinction permit a reliable resolution of combined or mixed absorption spectra. An example of the method of making such measurements and calculations is given in figure 2. The general procedure is a successive subtraction of calculated bands of known compounds from the observed mixed spectrum.

Measurements of the extinction at various wavelengths may be made by means of a conventional spectrograph, using photometric evaluation of the spectrogram. This method is, however, tedious and has so far been very little used in biochemical work. Spectrophotometry started with the construction of photo-electric cells by Elster and Geitel. Such cells, in combination with sensitive millivoltmeters, yielded excellent results in the hands of O. Warburg and his group [3], and served as a useful tool in their work on the *Atmungsferment*. For work with living material the

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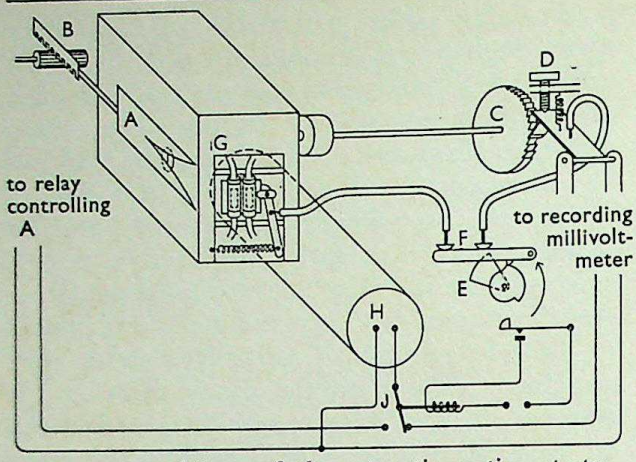

FIGURE 3 – *Scheme of the automatic grating spectrophotometer: A, diaphragm; B, gear connected to a balancing motor and a potentiometer for control of A; C, a wavelength timer set by the screw D and operated from a cam E which is driven by a synchronous motor. The lever F co-ordinates the operation of the wavelength timer and the sliding object-holder G. H, photomultiplier tube; J, device for alternate switching over of the photocurrent from recorder to balancing motor.*

sensitivity of the cells had to be still further augmented, and an instrument was also constructed by means of which flame photometry was developed as a method for studies in mineral nutrition [5]. Later on the introduction of photomultiplier tubes still further encouraged the construction of sensitive spectrophotometers [4].

In the last decade a number of manufacturers have placed convenient spectrophotometers on the market. Instruments made commercially, however, are as a rule adapted for general laboratory work, and a spectroscopist attacking special problems must still depend upon his own constructions.

A spectrophotometer capable of detecting the presence and activity of respiratory pigments in living material must show a high sensitivity, corresponding to an amplification of the primary current from the photocathode by a factor of 10^8–10^{10}. Photomultiplier tubes provided with a quartz window and 11–13 dynodes (total voltage 1500–2000 V) are as a rule sufficient for accurate recording of spectrograms from 15–25 mm thick layers of plant tissues (roots or storage tissue) or suspensions of yeast (5–15 per cent) and other micro-organisms in tubes of 20 mm diameter. The anode current may be still further amplified by an extra amplifier, but this is needed only under exceptional circumstances. Tungsten lamps (for the visible spectrum) and hydrogen lamps (for the ultraviolet) may be recommended as light sources.

Only recording instruments are of real use for studies of living material and, because of the lability of the steady states of oxidation-reduction, instruments that work rapidly are to be preferred. For recording extensive spectra, the instrument must be provided with a device for elimination of the varying spectral sensitivity of the photocathode. Different methods may be used for turning the varying intensity of the reference beam into a constant intensity over the whole measured spectral range, but they all divide the ingoing light into two beams, one for reference and the other for the sample. Adjustment of the reference beam may be made by regulation of the anode current, for example by means of a shunt. This method, however, introduces a possible error, because at high sensitivities the inevitable dark current of the photocell varies considerably with a change in the total resistance of the circuit. This error may be avoided by the use of an alternative method, the automatic adjustment of the intensity of the ingoing light by means of a movable diaphragm (see figure 3).

A disadvantage of instruments which draw a continuous spectrum on a strip of paper is the tedious and not very precise procedure of checking the wavelengths. The operator has to divide up

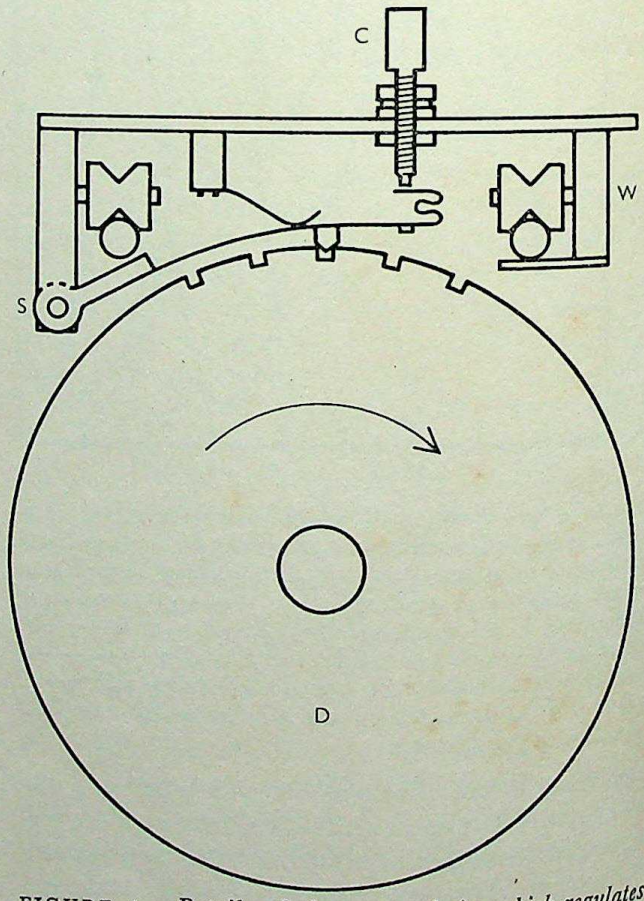

FIGURE 4 – *Details of the contact device which regulates the shift of wavelength positions of the quartz monochromator (cf. figure 5). D, drum; W, sliding carriage with a contact spring S and an adjustable pin C.*

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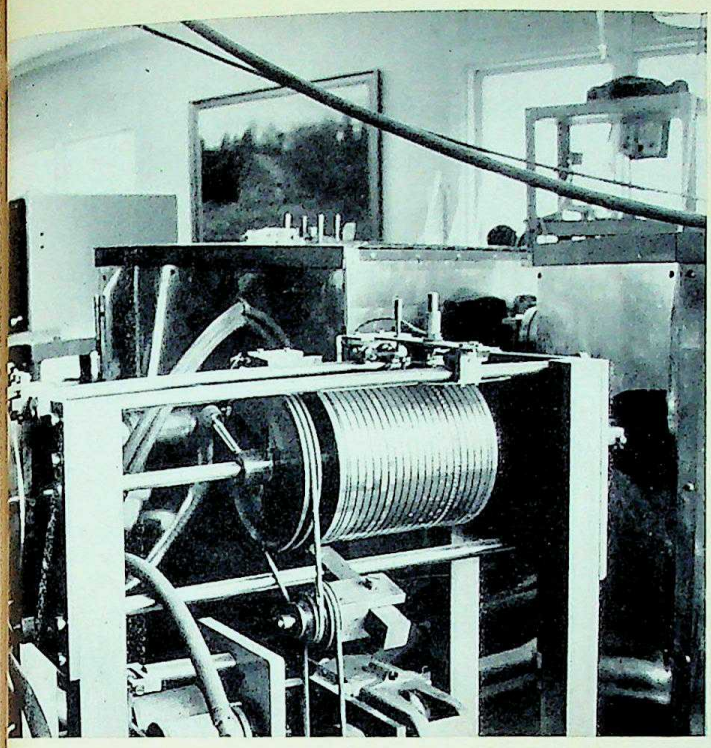


IGURE 5 – *Wavelength drum of the quartz spectrophotometer (for etails see figure 4). An electromagnetic clutch stops the movement of he drum each time the contact pin plunges into a notch. In this instrument, notches are cut at intervals of* 2 mμ. *Below the drum are the electromagnetic valves for the pneumatically regulated sliding object-holder.*

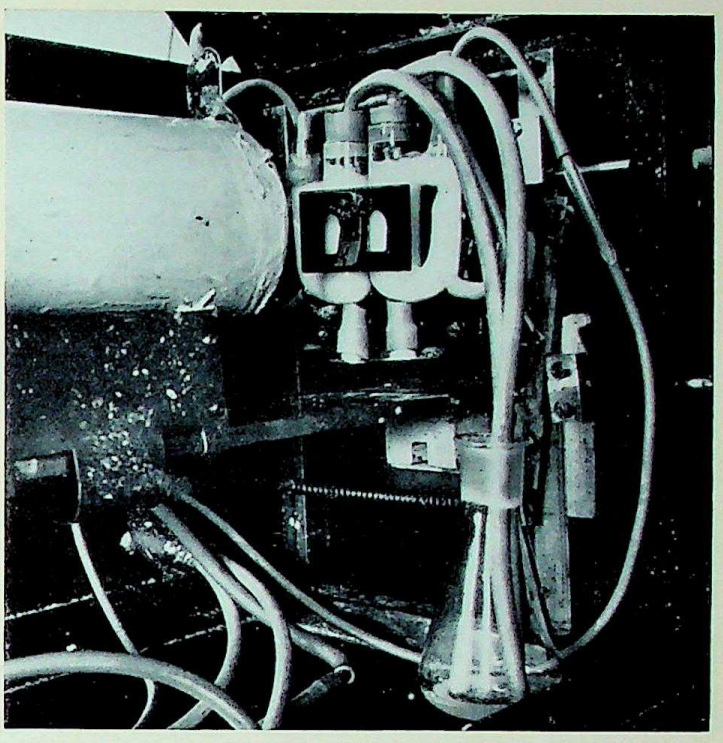
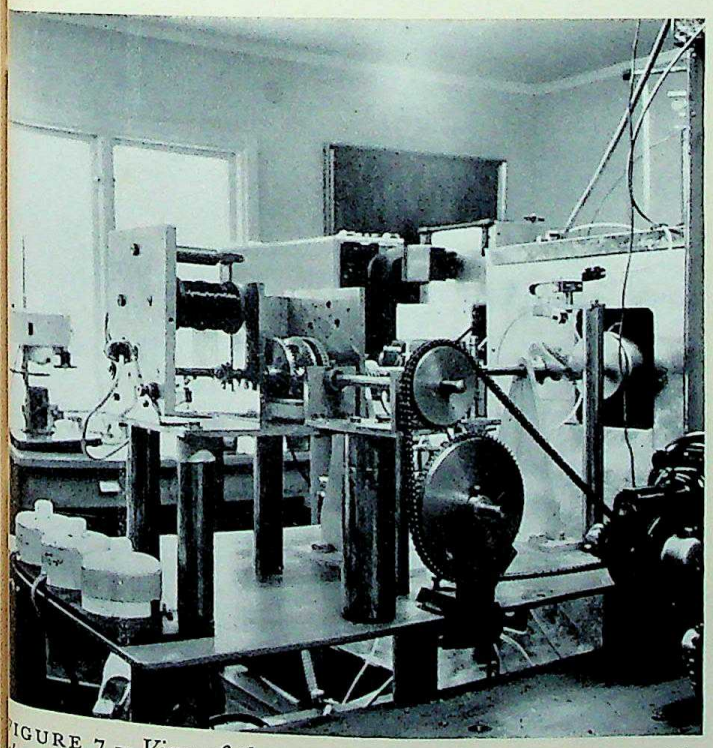


FIGURE 6 – *Details of the sliding object-holder (c.f. figure 3) which in this case carries two circulation vessels containing* 15 *per cent yeast, one aerated by* O_2, *the other by* N_2. *To the left is the photomultiplier.*



IGURE 7 – *View of the scanning device from the opposite side, howing the double bevel-gear and the transmission. To the left, the lectromagnet which reverses the movement of the bevel-gear. To he right, the device for suppressing the oscillographic image at ertain wavelengths.*

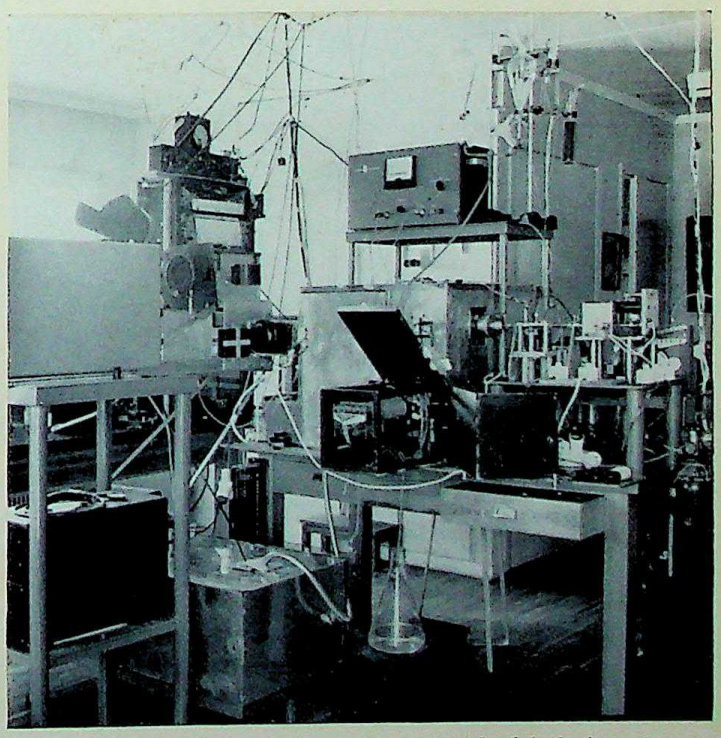


FIGURE 8 – *Grating monochromator mounted with the interchangeable devices for continuous or scanning recording. To the left, the oscilloscope with a camera, which is provided with gears for constant feeding of the film. Below, a shielded carriage containing the* 2000-*volt battery for the photomultiplier. Above, an extra amplifier, and arrangements for continuous flow of solutions or gases through the receiver.*

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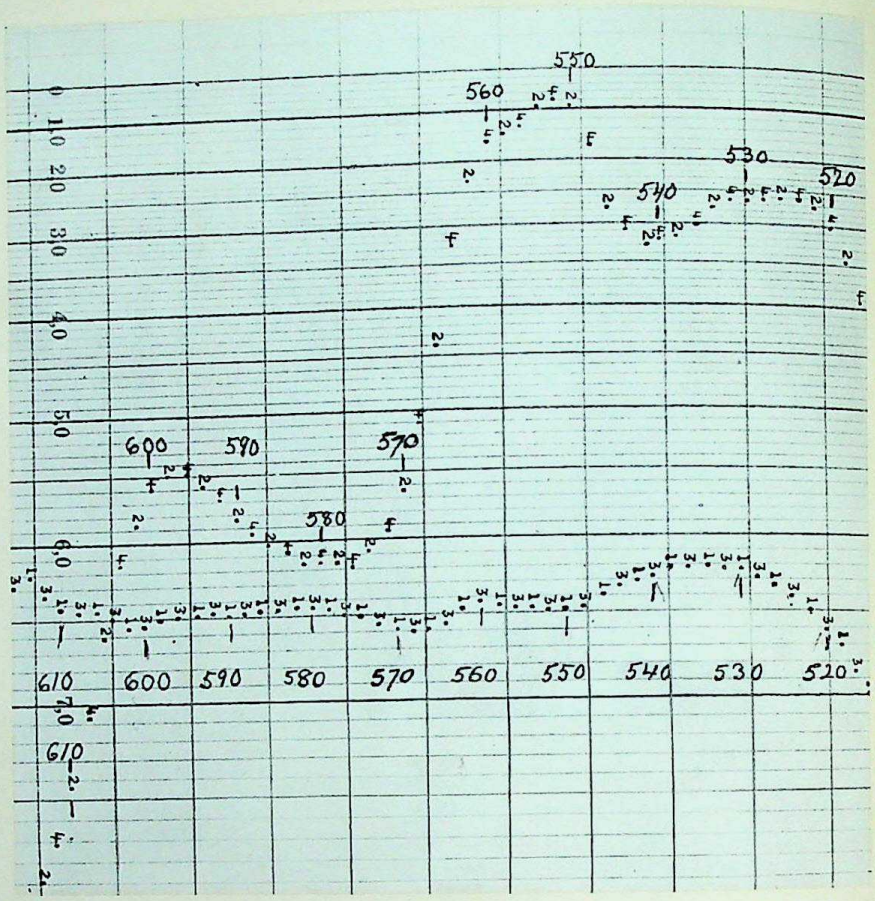

FIGURE 9 – *Record of a 4 mm thick cake of baker's yeast with eight layers of filter paper as the reference. Upper curve = sample; lower curve = reference* (ε = 1–2, 3–4). *The reference beam has been approximately equalized by means of the cam device.*

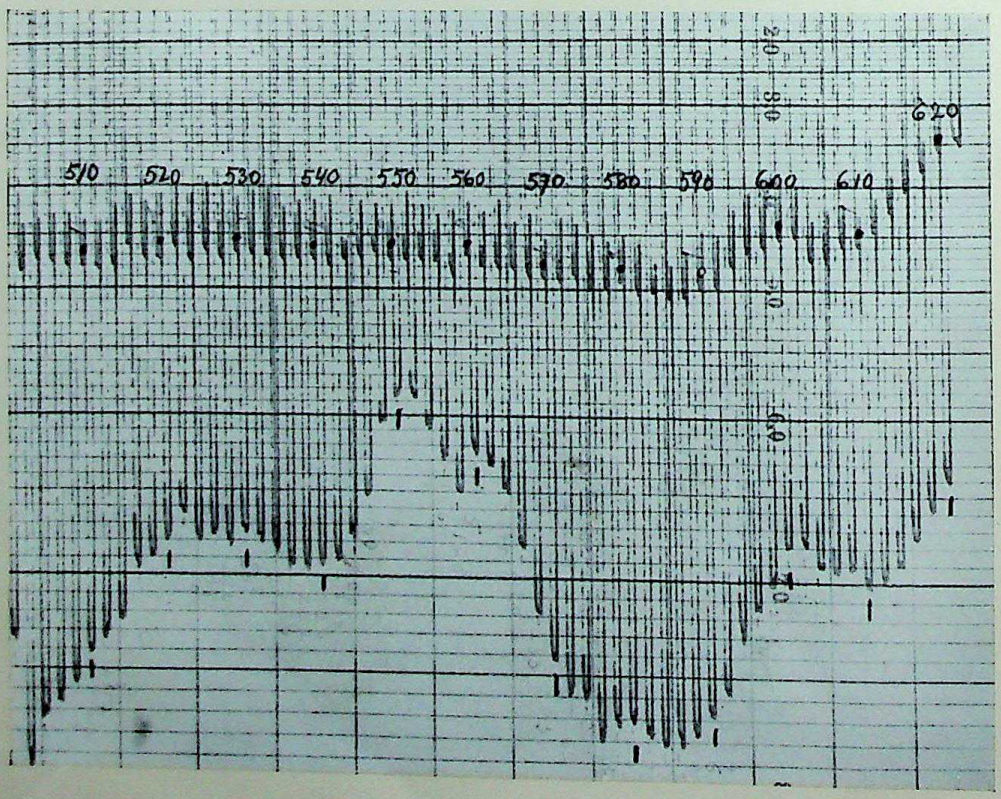

FIGURE 10 – *Record of a suspension of 15 per cent washed yeast, aerated with air (= reference: dots) or pure nitrogen (= sample: vertical dashes). Extinction in the difference spectrum is the difference between the points marked on the upper curve and the corresponding ones on the lower curve. The reference beam has been approximately equalized by means of the automatic device shown in figure 3.*

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the spectral curve by means of ruler and pencil, and the reproducibility of the measurements is not very good. Another disadvantage of instruments drawing a continuous curve is the hidden influence of the inertia of the millivoltmeter. Each meter has its minimum period of deflection, and a continuously moving pen will be completely balanced only when the recorder is moving comparatively slowly. Only oscillographic recording removes this source of error.

One possible way of avoiding these difficulties is to use instruments which divide the absorption curve into a series of single, individually recorded steps. In these instruments the wavelength drum is automatically moved in equal intervals of one or more millimicrons and full equilibrium of the voltmeter is established between steps. The construction of the instruments shown in figures 3 and 5 ensures that the wavelength positions of the drum are exactly reproducible, a circumstance that improves still further the accuracy of the measurements.

Of the two instruments constructed in the author's laboratory, one is provided with a quartz-prism monochromator, the other with a grating monochromator. Owing to the exponential decrease of the distance between the wavelength positions on the drum, which is characteristic of prism instruments, the stepwise movement requires a fairly complicated machinery, the details of which are shown in figures 4 and 5. The drum is provided with engraved furrows at each, or alternatively at every other, mμ-value. Each time a contact pin (see figure 4) drops into a groove the drum stops, always at exactly the same position. The timer steering the rhythm of the instrument starts the movement again and the next groove stops it, and so on.

A grating monochromator offers the advantage of equal divisions on the wavelength drum. Instead of the complicated machinery needed for the operation of the prism monochromator, the movement of the wavelength screw may be controlled simply by a toothed wheel. The intermittent shifting of the wavelengths in this instrument is performed mechanically by means of a flexible steel cable connected to a rotating cam device, shown in figure 3. The periods may be set at one or more seconds, and the mμ-values of the intervals may be changed freely.

The dotted curves drawn by one of these instruments (see figures 9 and 10) yield very reliable readings of the extinction and of differences of extinction between two wavelengths. The author's experience of spectral analysis of living material has taught him that curves recorded in 2 mμ intervals satisfy all demands for exact measurements of band heights. Intervals of 1 mμ may be chosen for special purposes, such as determination of the positions of peak values, but it is more important to know exactly the extinction values in 2 mμ intervals than to know the position of a peak, the value of which always varies somewhat according to the choice of slit width in relation to the dispersion of the instrument. A strictly quantitative comparison between two spectrograms is of course possible only if both are recorded at identical slit widths.

The classical way of measuring extinction ($\varepsilon = \log \{I_0/I\}$) implies separate measurements of intensities of the reference beam, I_0, and of the beam passing through the sample, I. It was mentioned above that some modern instruments substitute the recording of I_0 by automatic elimination of the sensitivity curve of the photocell. The operator has in this case to trust the guarantee of the manufacturer; he is unable himself to check the values of I_0. The intermittent operation of the author's spectrophotometers offers the possibility of checking the value of I_0 at each recorded wavelength. This brings another advantage, namely that it is not necessary to eliminate variations in the sensitivity of the photocell completely, a fact which makes possible a high speed of recording. If each value of I_0 is recorded, an approximate adjustment is quite sufficient, because the logarithmic difference between I_0 and I is measured for each individual wavelength. The readings and calculations are considerably facilitated if the paper is logarithmically divided (see figures 9 and 10).

The instruments are provided with a mechanical or pneumatic device for switching between reference and sample, as shown in figures 3 and 6. The adjustment of the intensity of the reference beam is performed just before the recording of I_0.

Because living material is more or less turbid and much light is lost by scattering, the reference beam must pass through a neutral substance of similar turbidity and scattering qualities to the sample. Layers of filter paper (such as 8–11 layers of Munktell No. 3), cotton wool, etc, have proved useful for this purpose. It is a familiar experience that the direct spectrum of the sample may be distorted as compared with the spectrum of clear solutions. Distortion is avoided if two oxidation-reduction states are recorded by difference spectra as I_0 and I respectively. The increasing reduction

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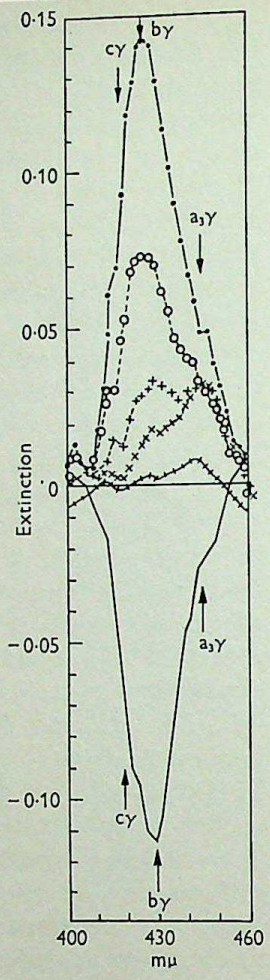

FIGURE 11 – *Example of resolution of the spectrum by means of intermittently recorded spectrograms as reduction proceeds. Material: a 14 mm thick bundle of wheat roots (drainage by aerated water, 0·2 cm³ per second). The spectrum of the aerated sample serves as reference. Time from shifting over the medium to an oxygen-free solution of succinate (positive curves): +++++ 1 min., x-x-x- 4 min, +--+-- 7 min., o----o 13 min., ·——· 32 min.; ——— reoxidation 1 min. after switching over to aerated solution (negative curve). It is clearly seen that reduction starts with the cytochrome oxidase ($a_3\gamma$ at 444 mμ), later followed by cytochrome b (bγ at 430 mμ). Wheat roots contain only little cytochrome c (cγ is visible at 416–418 mμ). On complete reduction (32 minutes from start), only a large fused band is seen, on which bands of cytochromes a_3 and c may be traced from small elevations.*

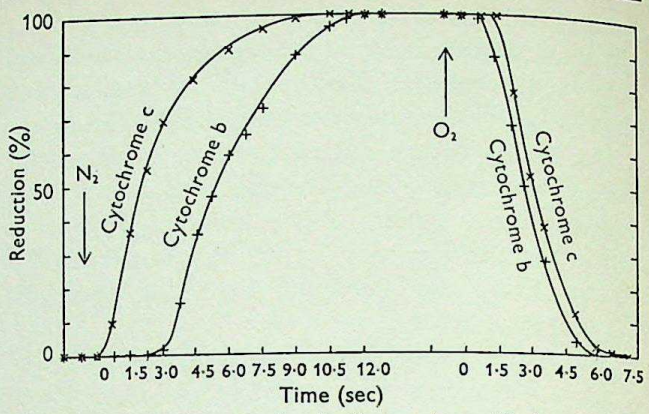

FIGURE 12 – *Course of reduction and reoxidation of cytochromes c and b recorded at 20° C with the oscillographic scanning device, spectra recorded in intervals of 0·3 sec. The extinctions are measured from the differences 550–546 mμ (for cytochrome c) and 562–570 mμ (for cytochrome b), for the sake of comparison, however, calculated in percentages.*

of bakers' yeast may thus be studied if one tube with oxygenated yeast suspension serves as the reference for a similar tube containing a suspension fed with nitrogen. The percentage increase of reduced cytochromes, pyridine nucleotides, and flavoprotein may be calculated from the difference spectrum according to the procedure mentioned above. For measuring the extinction of the single cytochromes, wavelength intervals are chosen in regions where the bands of the other cytochromes show a minimum of interference (see table 1 and figure 2). The quantity of interfering 'accessory' cytochromes may be approximately calculated from the deviations in the bands of adjacent well-known cytochromes: thus cytochrome c_1 can be estimated from the deviation of the extinction at 554 mμ from the calculated cytochrome c value. In calculations of the actual concentrations of enzymes in living material, due attention must be paid to the influence of the turbidity. Correction factors may be computed from direct measurements of the extinction caused by the addition of known quantities of pure enzymes to the turbid samples [6].

A valuable complement to the method of quantitative optical resolution of mixed spectrograms is the segregation of steady states brought about by changes in the degree of oxygenation or by the influence of specific inhibitors. Cytochrome b may thus be 'optically purified' by addition of antimycin A, which inhibits the reoxidation of this cytochrome. Observation of the characteristic pattern of reduction is also of great value. Cytochromes a_3 and c start the reduction, cytochrome b and flavoprotein follow (figures 11 and 13). The time sequence is commonly reversed at reoxidation. The characteristic rhythm during increasing reduction of the respiratory system may be interpreted as a reflection of the spatial organization. The individual enzymes are apparently reacting with one another in multimolecular groups which are, at certain points, joined by accessory substances or 'factors', some of which may be related to vitamins.

Because of the complexity of the total respiratory chain, a complete analysis of its properties requires the recording of fairly complete spectrograms. The speed of the recorders is also a factor of importance. Details of the rapidly changing steady states may be surveyed if an instrument is used which records the region 520–620 mμ (covering α- and β-bands of most cytochromes) in 100–200 seconds. Rapid changes in the steady states of single enzymes may be followed by continuous recording of the difference between two wavelengths [7]. For similar purposes, direct recording of the peaks may also be used [6].

Large portions of the spectrum may be extremely rapidly recorded by means of an oscillograph. In the scanning spectrophotometer the spectrum is flickered on to a photocell attached to

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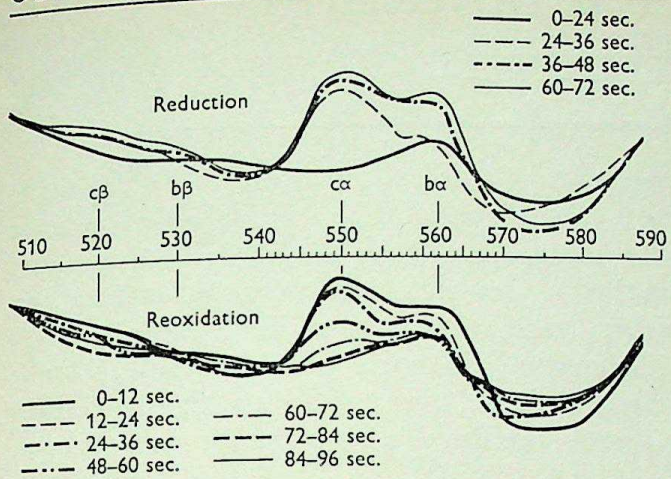

FIGURE 13 – *Slow scanning (period 12 seconds) of the processes of reduction and reoxidation of a sample of 15 per cent washed yeast, enclosed in a circulation vessel and aerated by nitrogen (for reduction) or air (for oxidation) at 5° C. Records made by a rapid Speedomax G recording millivoltmeter. The slower start of reduction of cytochrome b, as compared with that of cytochrome c, is clearly shown, as is also the gradual shift of extinction above or below the isosbestic line (for comparison see the changes of the spectrum of isolated cytochrome c in figure 11). At reoxidation the timing is reversed, cytochrome b going ahead of cytochrome c.*

an oscillograph. Series of spectrograms may thus be recorded in fractions of a second. Because of the noise which always to some extent disturbs measurements at these extremely high amplifications of the photocurrent, it is not advisable to go below about one-tenth of a second, however. According to the author's experience, intervals of $\frac{1}{3}$–$\frac{1}{2}$ second (see figure 12) are sufficient for accurate recording of changes in the steady states of micro-organisms upon removal or addition of oxygen and useful observations may even be made at intervals of 10–12 seconds if the processes are slowed down by cooling the containing vessel. A simple and convenient instrument for scanning work is shown in figure 7. An electrically operated double bevel-gear moves the wavelength screw to and fro. The length of spectrum recorded may be chosen at will, but a practical limit is set by the shape of the sensitivity curve of the photocell. For still more rapid work, scanning of the spectrum may be effected by a rotating or oscillating mirror which is placed between the collimator lens and the outgoing slit of the monochromator.

Examples of the usefulness of the scanning spectrophotometer are shown in figures 12 and 13. The pattern of reduction and reoxidation of the respiratory system of living material is difficult to explain unless it is assumed that the enzymes are operating in multimolecular units which are reacting with one another at spatially fixed points or surfaces. The method is thus a useful tool for tracing the existence of a spatial organization of the enzyme systems. Spectrophotometry may also reveal the influence of spatial organization on the molecular stoichiometry. Observations pointing to such influences, which may cause shifts in band positions, have been made in connection with studies of coenzyme 1 [6] and of photosynthetic pigments [8]. The variation of the band positions among haemin enzymes may also depend upon a variation of, or, alternatively, in the mode of connection to, the apoenzymes. Only three or four different haemins are known as prosthetic groups of respiratory enzymes, whereas the number of corresponding enzymes is considerably larger. The elucidation of these problems is, however, largely dependent on future progress in preparative and organic chemistry.

REFERENCES

[1] KEILIN, D. *Proc. roy. Soc., B*, **98**, 312, 1925.
KEILIN, D. and HARTREE, E. F. *Ibid., B*, **122**, 298, 1937.

[2] JAMES, W. O. 'Plant respiration'. Clarendon Press, Oxford. 1953.
Idem. Advanc. Enzymol., **18**, 281, 1957.

[3] WARBURG, O. *Angew. Chem.*, **45**, 1, 1932; 'Schwermetalle als Wirkungsgruppen der Fermente'. Berlin, 1946.

[4] FRENCH, C. *Carnegie Inst. Wash., Yearb.*, **53**, 182, 1954.
DUYSENS, L. *Science*, **120**, 393, 1954.
WITT, H. *Naturwissenschaften*, **3**, 72, 1955.

[5] LUNDEGÅRDH, H. 'Die quantitative Spektralanalyse der Elemente', Vols. I and II. Jena, 1929–34. 'Die Nährstoffaufnahme der Pflanze'. Jena. 1932. 'Leaf Analysis.' London, 1951.

[6] *Idem. Ark. Kemi*, **5**, 97, 1952; **7**, 451, 1954.
Idem. Nature, Lond., **171**, 521, 1953.
Idem. Biochim. Biophys. Acta, **20**, 469, 1956; **25**, 1, 1957; **27**, 355, 653, 1958.

[7] MILLIKAN, G. A. *Proc. roy. Soc., B*, **123**, 218, 1937.
CHANCE, B. *Science.*, **120**, 767, 1954.

[8] JACOBS, E. E., HELT, A. S., KROMHOUT, R., and RABINOWITCH, E. *Arch. Biochem.*, **72**, 495, 1957.
LATIMER, P. *Science*, **127**, 29, 1958.
SMITH, H. C., KUPKE, D. W., LOEFFLER, Y. F., BENITEZ, A., ARNE, I., and GIESE, T. 'Research in Photosynthesis', p. 464. 1957.

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Brazilian insect adaptations

H. B. D. KETTLEWELL

Eastern Brazil gave Charles Darwin his first experience of tropical forest and its inhabitants and contributed to the formulation of his theory of evolution. The author of this article has lately visited the same region to study insect adaptations there in the light of modern genetical and evolutionary theory. He suggests that a very rich flora may account for the large insect fauna, and that long-standing environmental stability may have permitted the preservation of frequent extreme specialization. Increased biological pressure resulting from the existence of an almost infinite number of biological niches, together with a high predation rate, may, the author concludes, be a further reason for Brazil's remarkable insect fauna.

If we wish to meet some of the most extreme forms of specialization in life it is probably true to say firstly, that they can be found among insects; secondly, that these will be tropical insects; and thirdly, that they are likely to occur in those equatorial regions of the world that have been subjected to no extreme climatic changes in the recent past. On these assumptions, conditions in Brazil are exceptionally favourable. It was here that in 1832 Charles Darwin, at the age of twenty-two, was for the first time in his life confronted with tropical forest and its inhabitants. It is clear from his 'Journal of Researches' [1] and his 'Origin of Species' [2], though less so from his 'Diary of the Beagle' [3], that the insects of Brazil made a great impression on him: the Lampyridid phosphorescent beetle; the Ageroniid butterfly which 'clicked' in flight; the Army ants and their behaviour; the Pepsis wasps. Nevertheless, he wrote in the 'Journal' the following revealing sentence: 'The large and brilliantly coloured Lepidoptera bespeak the zone they inhabit, far more plainly than any other race of animals. I allude to only the butterflies; for the moths, contrary to what might have been expected from the rankness of the vegetation, certainly appeared in much fewer numbers than in our own temperate region.' This is a most poignant sentence, because on the one hand it suggests Darwin's quite natural inability to assess, at that time, the significance of conspicuous butterfly patterns. On the other, it admits the efficiency of the camouflage of the multitudinous cryptic (camouflaged) moths which so successfully hid from him by day: modern collecting methods have made an appreciation of them much easier.

It is indeed unfourtnate that Darwin had initially to meet what were probably the most complex inter-relationships to be found amongst insects in the world. His main interests in Brazil were, however, centred on orders other than the Insecta. At a later date, much of what he had observed was interpreted scientifically, in agreement with his own views, by Alfred Russell Wallace [4] who had been collecting on the Amazon, which, incidentally, Darwin never visited. Wallace, in contrast to Darwin, arrived at his concept of Natural Selection and the evolution of one species from another, largely as the result of studying insects.

Last year the centenary of the joint Darwin-Wallace paper [5] was celebrated and I was fortunate enough to be sent out to visit the same places in Brazil as Darwin went to in 1832. My assignment was to attempt to evaluate in the light of modern genetical and evolutionary knowledge the insect adaptations found there, and to photograph them in their natural habitats. I was also able to compare these with insects found in other tropical forests of which I had had previous experience, such as those of the Belgian Congo, Uganda, and Portuguese East Africa.

Before attempting to analyse my findings it must be stated that after only a few weeks I became acutely conscious of basic differences between Brazilian insects and those I had studied in other parts of the world. These differences may be enumerated as follows: firstly, that in a given habitat of equal area there appeared to be a greater number of species; secondly, that amongst these species, a high proportion fell into the category of extreme specialization; thirdly, that species with more than one line of defence were frequent; and lastly, that whenever an insect depended upon one line of defence alone, such as crypsis, it had to approach perfection. Even so, I was impressed with frequent examples of perfect adaptations whose defences must have been

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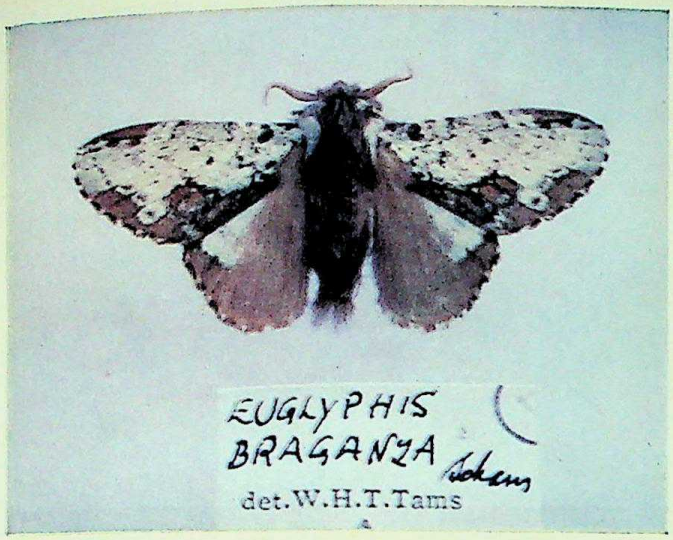

FIGURE 1 – Euglyphis braganza *Schaus* (*dead set*). *The use of adaptive colouration. Note patterned hindwing.* (×2)

FIGURE 2 – Euglyphis braganza *Schaus* (*alive*). *Cryptic colouration: use of patterned hindwing.* (×2)

FIGURE 3 – Scanthops falcatara *G. Cryptic colouration. Mantid mimicking dead leaf.* (*Natural size*)

FIGURE 4 – Topana media *Walker. Simple cryptic colouration. Orthopteron copying green leaf with brown blemish.* (×3)

FIGURE 5 – Phylloptera *species. More complex cryptic colouration. Orthopteron copying leaf with mould-like markings.* (*Natural size*)

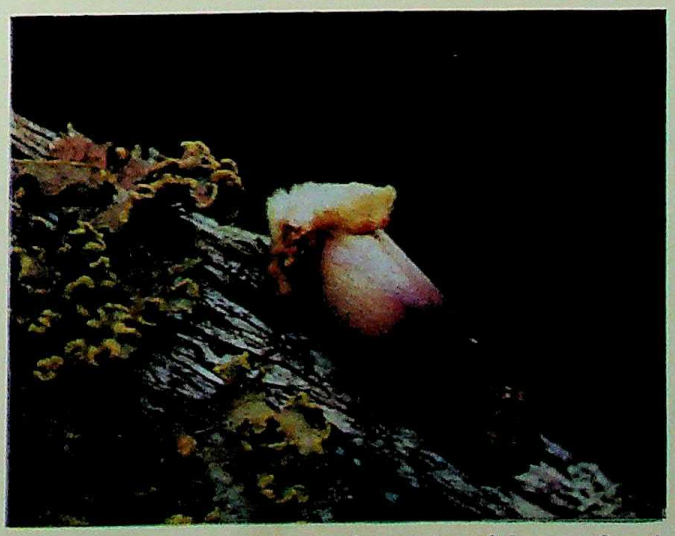

FIGURE 6 – Cossula notodontoides *Schaus. Cryptic colouration. Moth mimicking a fallen flower.* (*Natural size*)

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FIGURE 7 – Lirimiris lignitecta *Walker. Cryptic moth mimicking broken twig.* (×2)

FIGURE 8 – Automolis angulosa *Walker. Simple disruptive pattern. Note alternate black and white stripes.* (*Natural size*)

FIGURE 9 – Thysania *species. Cryptic plus disruptive colouration. Note black stripe parallel to bark markings.* (×$\frac{1}{3}$)

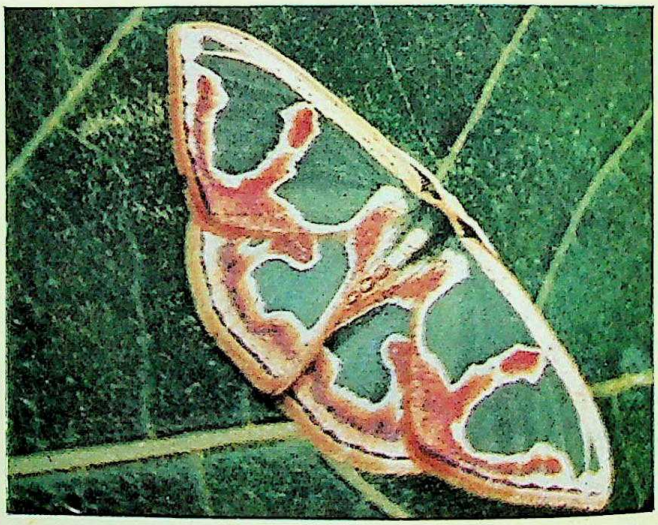

FIGURE 10 – Anophylla magnifica *Schaus. Disruptive pattern—bird excreta.* (×2)

FIGURE 11 – Loxolomia serpentina *M. and W. An example of perfect shading. This species copies a piece of dead and loose bark.* (×$\frac{1}{2}$)

FIGURE 12 – *An unidentified Sphingid larva. A perfect example of counter-shading.* (×$\frac{1}{2}$)

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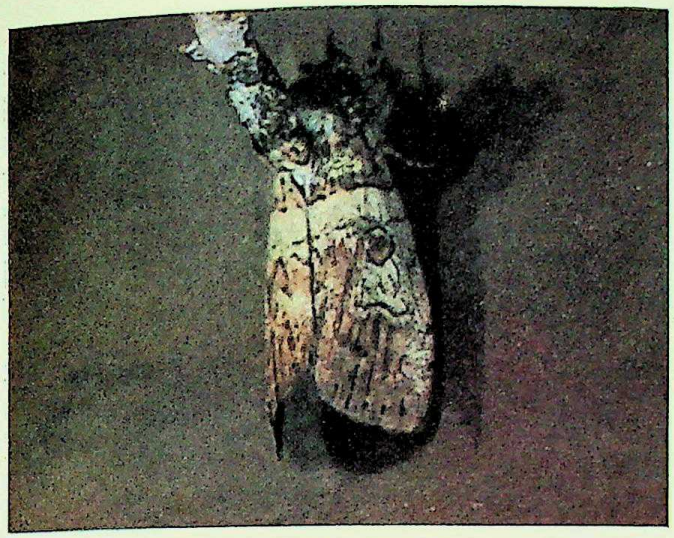

FIGURE 13 – Casandria erratica *D. Jones. Importance of position (abdomen). Note patterned ventral surface.* (×2)

FIGURE 14 – Trosia dimas *Cramer. Warning colouration.* (×2)

FIGURE 15 – Macroneme immanans *Hmpsn. Batesian mimicry. Moth mimicking wasp.* (×2)

FIGURE 16 – Phoebetron (Euclidae) *larva. Batesian mimicry. Larva mimicking spider.* (×2)

FIGURE 17 – Ommathoptera pictifolia *Walker. Three lines of defence. Display of 'secondary eye-marks'.* (*Natural size*)

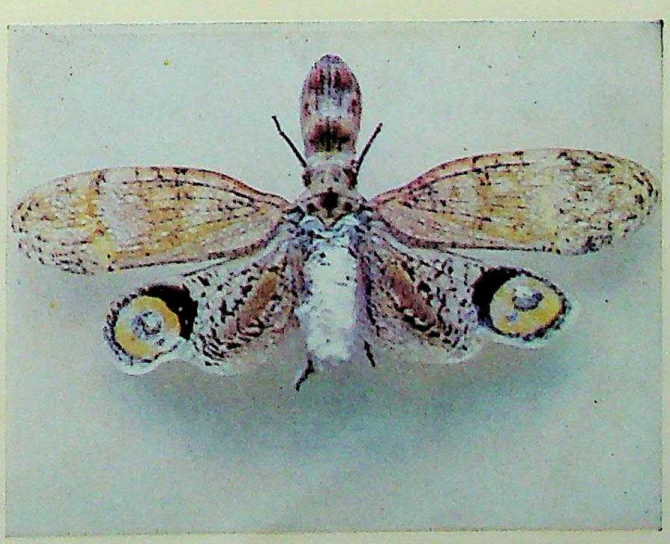

FIGURE 18 – Laternaria phosphorea. *Four lines of defence. 'Horror mask.'* (*Natural size*)

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FIGURE 19 – Tanusia brullaei *Blanchard*. *Orientation to sun.* (*Natural size*)

FIGURE 20 – Perola brumalis *Schaus*. *Importance of position* (*legs*). (×2)

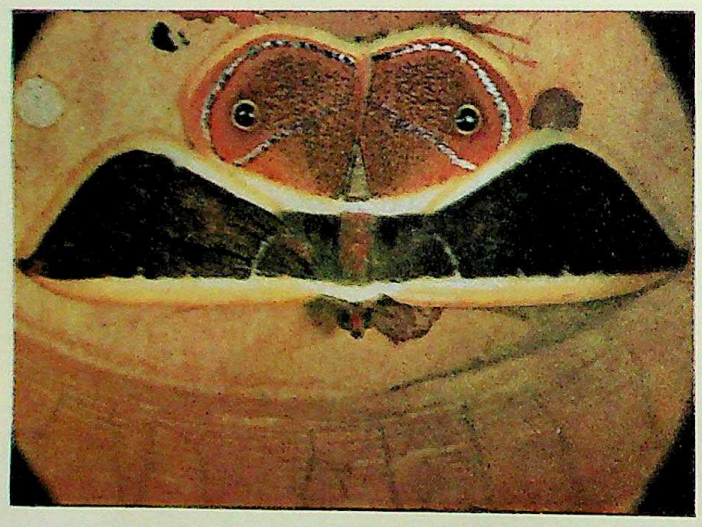

FIGURE 21 – Opthalmophora claudiaria *Schaus*. '*Primary eye-marks*.' *Threat*. (×2)

FIGURE 22 – Megalopygid *larva*. *The use of hair*. (×2)

FIGURE 23 – Trichomoplata cassiope *Schaus*. *The use of bristles*. (×2)

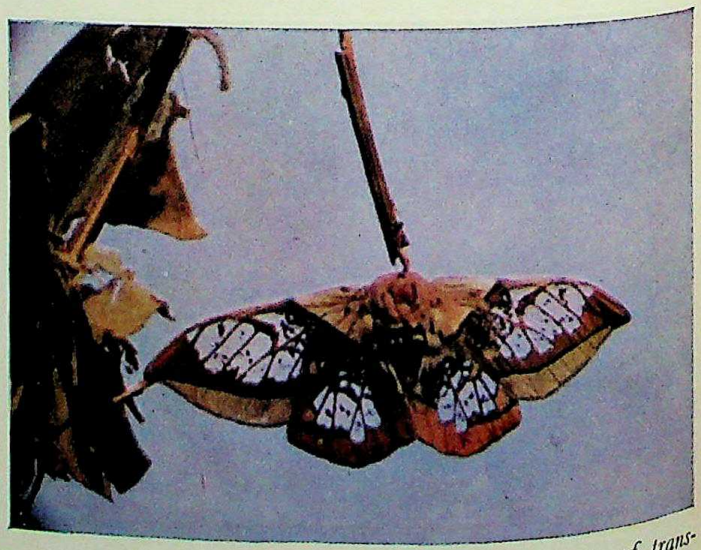

FIGURE 24 – Syssphinx basirei *Schaus*. *The use of transparency*. (×½)

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penetrated sufficiently often to permit one or more additional lines of defence to have been selected. Some species have as many as four, each equally efficient, and each coming into play in succession, according to the seriousness of the situation or the degree of aggressive stimulus provided. Colour and pattern, therefore, go hand in hand with extremely specialized types of behaviour, the one depending on the other, and in insects these must all be inherited and can be to only a small degree, if at all, the result of previous experience, such as affects the behaviour of higher animals.

These impressions—and they must be considered no more than this—would obviously have interesting biological implications if substantiated. One of the objects of this paper is to point out the difficulties of interpreting one's findings quantitatively in order to make a strict comparison between the insect fauna of tropical South America and those found elsewhere. I hope to show that unless one is aware of the whole of the behaviour pattern that a given species follows both by day and by night, it is useless to speculate how 'specialized' it is, or whether a particular pattern is adaptive or otherwise.

A good example of this is provided by *Euglyphis braganza* Schaus. When dead and mounted (figure 1) this very ordinary-looking moth is remarkable for one thing only, namely for having a white pattern on the costa of the hind-wing, an unusual position for patterning. This becomes intelligible only when the insect is seen alive at rest (figure 2). In common with others of the same genus, this moth has a habit of passing the day motionless on tree trunks, with the anterior border of the hind-wings projecting beneath, and in front of, the forewings. The adaptive significance of this hind-wing pattern now becomes apparent: it blends with the white markings of the fore-wings and the advantage of this is that the protruding hind-wings tend to break down the outline of the moth and merge it into the patches of white lichen on which it sits.

Examination of dead specimens or insects caught in traps, tells one very little about the uses to which they put their patterns and nothing about their behaviour, which is an integral part of the whole. I have therefore attempted to depict the insects as I found them in life and to classify their defensive mechanisms according to my interpretation of them. Up to a point, this agrees with the analysis of H. Cott who visited Brazil, amongst other places, and who published his very comprehensive work on adaptive colouration [6] in 1940. H. W. Bates [7, 8], Miles Moss [9], C. L. Collenette [10], W. S. Bristowe [11], P. Poulton, and others have recorded various aspects of Brazilian insect specialization, but most of them have confined their evidence to individual problems. Table 1 classifies the Brazilian insect adaptations as I found them in nature, from the simplest to the most complex. There must, nevertheless, be a direct relationship between the degree of edibility and the extent of the specialization.

TABLE I

Classification of insect adaptations found in Brazil.

1. One Line of Defence
   - (*a*) Simple crypsis (camouflage).
   - (*b*) Disruptive colouration.
   - (*c*) Primary 'eye-marks'.
   - (*d*) Warning or aposematic colouration.
   - (*e*) Müllerian mimicry.
   - (*f*) Batesian mimicry.
2. Two Lines of Defence
   - (*a*) Secondary warning mechanisms (hidden colour signals).
   - (*b*) Secondary 'eye-marks'.
   - (*c*) Flash colouration.
3. Three Lines of Defence
   - (*a*) Crypsis: dazzle and 'eye-marks' (*O. pictifolia*).
   - (*b*) Crypsis: flash: sting (*A. ganascus*).
   - (*c*) Crypsis: distasteful wax: 'eye-marks': 'horror-mask' (*Laternaria phosphorea*).
4. Other specializations (miscellaneous)
   - (*a*) Use of position (i) orientation to sun (ii) legs, body, wings, etc.
   - (*b*) Use of blue scales.
   - (*c*) Use of hair.
   - (*d*) Transparent wings.
   - (*e*) Great size.
   - (*f*) Use of tails.
   - (*g*) Phosphorescence.
   - (*h*) Mirror reflection.

Furthermore, palatability must vary from time to time according to supply and demand. When one species has become extremely abundant because of an unpalatable quality, it is usual to find that some particular predator has adapted its feeding habits to take advantage of the situation. An obvious example of this is seen in the ability of the European cuckoo (*Cuculus canorus* L.) to feed on poison-haired larvae, which are its principal diet: it has a mechanism for regurgitating poisonous hairs as pellets. The actual flesh of many nauseous creatures is, in fact, attractive. A particular defence, therefore, is answered by an equally specialized attack; in Brazil, undisturbed by any recent major climatic change, this has been carried to extremes. Though there is ample

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evidence that the South American continent has undergone vertical shifting, there has certainly been no glaciation in Brazil since the Pliocene.

ONE-LINE DEFENCE

With these thoughts in mind, we will consider some of the 'one-line defence' insects that depend on crypsis alone. L. de Ruiter [12] has shown that when European jays (*Garrulus glandarius* L.) were fed on caterpillars that mimic twigs, together with a number of actual twigs from the trees on which they were found, the birds' interest was proportionate to the number of insects presented compared with twigs. It therefore follows that—as in any forest there are more leaves, dead and living, than twigs, and more twigs than boughs or trunks—leaves would offer more unsuccessful encounters than twigs, even having regard to the surface areas presented. It is not surprising, therefore, that a very large number of species of insects copy both dead brown leaves and living green ones. An excellent example of the former is *Scanthops falcatara* G., the Brown Mantid (figure 3). It escapes predation by its similarity to a dead leaf, and also gains advantage from the deception by permitting other insects on which it feeds to approach it unawares.

Many species of moth copy dead leaves by presenting a longitudinal stripe from tip to tip, which simulates the midrib. Others have wings with edges that are 'eaten out' but still successfully obey the laws of aerodynamics. In the pattern many include copies of leaf blemishes, holes, and mildews which appear as brown, transparent, or whitish spots. The moth *Meticulodes spongiata* Guen., inverts the costa of its forewings and rolls them up into hollow tubes, giving the impression of a shrivelled leaf. I also found a single specimen of a small Geometrid moth which held its brown wings asymetrically when at rest; the tip of one turned up and the other down. On touching this moth, to my surprise it dropped off, and, revolving rapidly, it went spinning away like a sycamore seed.

Simple green-leaf mimicry is well demonstrated by the Orthopteron *Topana media* Walker (figure 4) and in addition brown blemishes are to be seen upon it. In a *Phylloptera* species (figure 5) white mould marks are evident and it is extremely difficult to find except at night. A large number of Lepidoptera in Brazil look like green leaves, but the majority have additional markings for disrupting the outline or presenting blemish-like spots on them. The moth *Cossula notodontoides* Schaus (figure 6) mimics a fallen flower and sits exposed: it is a rare species. Dead wood and twigs are frequently copied. One of the most perfect examples of this is the moth *Lirimiris lignitecta* Walk (figure 7). The broken end of a twig is sculptured to perfection by the modification of the head and thoracic structures.

Simple disruptive patterns, which break up insect outlines, are common in the tropics. The bright vertical sun permits the exploitation of alternate black and white stripes as is seen, in its simplest form, in *Automolis angulosa* Walk (figure 8). An extension of the same principle is found in many moths which combine disruptive stripes with crypsis. All these spend the day at rest in such a way that the stripes run parallel with the vertical lines on the bark (figure 9). In certain species this demands that the moths sit sideways on the trunk, which they unfailingly do. This then, is another example in which a specialized pattern requires a specialized behaviour. Figure 10 shows a Geometrid moth with a beautiful and complicated disruptive pattern. It sits exposed on the surface of green leaves, looking like old bird-excreta; many species mimic this, some to an incredible pitch of perfection. Specialized shading is seen in the moth *Loxolomia serpentina* M. and W. (figure 11) which spends the day at rest, looking like a piece of loose bark. Countershading is beautifully demonstrated by an unidentified Sphingid larva (figure 12). The vertical tropical sun also permits it to have bright white splashes which simulate the light reflected from the shining leaves of its food plant. This larva always sits upside down; when the dorsal surface is deliberately placed uppermost it becomes conspicuous.

All the insects so far discussed and depicted have depended for their survival on crypsis—perfect camouflage. Another one-line defence mechanism is found in insects that reproduce 'eye-marks' as a conspicuous feature of their pattern. Those that we are about to discuss here have them permanently on view, often on the forewings. I therefore refer to these as primary eye-marks, and this defence and its uses must be kept distinct from another in which insects have life-like 'eyes' but normally keep them concealed, exhibiting them only on attack. These will be referred to later under the heading of secondary eye-marks.

Primary eye-marks, which are frequently of small size but nevertheless perfect, have two distinct uses. Firstly, the larger ones may serve to threaten and frighten away predators; secondly, the smaller ones act as 'deflection spots.' For the

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latter use they must always be situated distally, and as far away as possible from the vital areas of the body: the 'eyes' then invite attack on unimportant structures. This mechanism is found commonly among Brazilian butterflies, usually on the underside of the wings and hence only of use whilst at rest. Figure 21 shows the moth *Opthalmophora claudiaria* Schaus in which the eye has been selected to a very high degree of perfection, complete with pupil light reflection. In this instance it is probable that it serves as a threat mechanism.

Another threat mechanism, usually referred to as warning or aposematic colouration, is common among Brazilian insects. It leads to some of the most complicated and sophisticated insect relationships in the world. Its general principle is precisely the opposite to that of crypsis: it depends on revealment instead of on concealment. In its simplest form an insect with some unpleasant quality, such as nauseous taste or smell, makes itself conspicious with the object of reminding its predators, by association, of previous unpleasant encounters. The moth *Trosia dimas* Cramer (figure 14), with its red domino-like pattern, is an example of this. I found it had a most unpleasant taste and smell.

It is not therefore surprising that many insects that have distastefulness in common have been selected to have similar patterns. They all wear a conspicuous and similar uniform. An unpleasant experience gained from one species will give protection to others. Usually the warning colours are black and red, or black and yellow, sometimes white. This defensive mechanism, in which numbers of different distasteful species, similar in appearance, fly together, is known as Müllerian mimicry.

An extension of the same principle is found in which certain species of insects, whilst themselves palatable, masquerade under the warning guise of others that are not and fly with them. These are referred to as Batesian mimics. It is the usual rule, but depending on the degree of distastefulness of the model, that in any assemblage, the Batesian mimics must not outnumber the Müllerian, or the system would break down. This situation is found commonly on the Amazon, where large numbers of different species of butterfly congregate together on the damp tracks used by humans.

Another type of Batesian mimicry is found in which warning colouration plays no part. Many different kinds of insects mimic, to a quite remarkable degree, specific creatures universally accepted as dangerous. The moth *Macroneme immanans* Hmpsn., for example, mimics a black ichneumon wasp with which it flies (figure 15). Others, both moths and larvae, copy spiders. When I first found the caterpillar of a *Phoebetron* (*Euclidae*) species (figure 16) I could not decide immediately even to which order it belonged. It has eight fleshy appendages which if torn off regenerate on moulting, and it sits exposed like a large spider on the surface of a leaf. The male Psychid moth *Oiketicus kirbyi* G. has an enlarged first pair of legs and a greatly extended abdomen which, on attack, it telescopes in and then out again: the overall effect is scorpion-like. Several species of beetle mimic ants with which they live, thereby gaining protection. In all these Batesian mimics it is not enough that colour and pattern should match those of the model. The mimic must conform also to the specialized behaviour patterns.

One last and previously unrecorded example of Batesian mimicry must be given. *Cecropia* tree species are common in Brazil and are characterized by having hollow trunks and an association with ants, which frequently cover the leaves. Whilst working in the Corcovado Forests with E. P. Wiltshire we found a mass of oily and heavily spined caterpillars on the underside of a leaf. They were the larvae of *Gynaecia dirce*, a well-known Brazilian butterfly. They appeared to be immune from the attack of ants, which abounded everywhere. These larvae have the usual number of legs and walk in the usual manner. On disturbing these larvae by picking the leaf on which they were resting, we noticed another larva of similar appearance and pattern among them, but which 'looped' on walking. It was the larva of an entirely different species, a Geometrid moth. On closer examination we found that the spines of the butterfly larvae were copied by fleshy outgrowths on the Geometrid larvae. Unfortunately, the Geometrid larva died and no other examples were found, as it was too late in the season. Presumably it gained protection whilst feeding on the *Cecropia* by living with the larvae of this protected butterfly. It is interesting to reflect on how the larvae of a Geometrid moth can succeed in establishing itself in the midst of those of a *Nymphaline* butterfly.

Every survival mechanism described so far has relied on one line of defence only. When this is penetrated, the insect's defensive repertoire is exhausted and death is the inevitable result.

TWO-LINE DEFENCE

Many insects have developed two or more lines of defence. In its simplest form this is seen in

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various threat or warning reactions which come into play when the crypsis has failed and the insect is attacked. Commonly the hind-wings or abdomen are exposed and the colours red or yellow are flashed at the predator; this always goes with a special behaviour pattern, such as rhythmic displays or feigning death. Some species, such as *Syssphinx molina* Gram. display a single black spot in the middle of a brightly coloured area. This is the most likely origin of the hind-wing eye-mark in which an eye is copied to a quite remarkable degree of perfection in certain South American moth genera, such as the *Automeris*. I refer to these as secondary eye-marks. D. Blest [13] has shown in aviary experiments that the acceptance or refusal of these moths as an article of diet by birds is decided by the perfection of the eye-mark. In my opinion it is likely that the perfect eye has been built by natural selection in a series of stages, probably commencing with a plain black spot. We have evidence from the British Lepidoptera that a single gene can so alter a circular black spot that it appears as a shaded area with a thin rim of black retained around the circumference (in a form of *Arctia caja*). A second gene is responsible for a contrasting ring running round the outside of this, and yet another for the light reflection seen on the 'pupil' (in *Saturnia pavonia* L.). No doubt several genes become linked by natural selection, the whole forming a super-gene which in effect works as one unit. All gradations of eye-marks are found in Brazil, the majority having great perfection of detail.

I was able to carry out a short series of releases of *Automeris* moths and other species with secondary eye-marks. These were undertaken at daybreak, which is the main feeding time for the majority of birds. I was greatly surprised to see that, when discovered, the moths were seized and carried away in a flash: they appeared to have no opportunity of bringing their eye-mark mechanism into play. Subsequently I was able to follow a bird and noted what happened. In order to peck and eat the moth it was, of course, necessary to drop the insect on the ground; the moth then flashed its eyes and the bird recoiled and the moth escaped. On a further occasion I saw an *Automeris* moth escape after being carried away, but I was unable to see the details of how it managed it. I have little doubt that this is the normal method of use of the secondary-eye mechanism. Strangely I found no *Automeris* species showing beak marks.

Another two-line defence mechanism, flash colouration, is found commonly, particularly among Brazilian Acrididas, Cicadidae, and Lepidoptera. The forewings are cryptic, but when the insect takes flight the brilliant scarlet, yellow, or blue hind-wings command attention. On alighting, they become inconspicuous again and merge with their background.

THREE OR MORE LINES OF DEFENCE

Many insects have developed more than two lines of defence. The highly cryptic Orthopteron, *Ommathoptera pictifolia* Walker, at rest, looks exactly like a dead leaf. On being disturbed it quivers its wings rapidly, exposing the multicoloured underside, and this produces a confusional effect. Finally it throws its wings open and exposes two eye-marks (figure 17).

The Sphingid moth, *Amplypterus ganascus* is cryptic, with a disruptive pattern. When attacked it exposes its red hind-wings, and if picked up this moth 'stings': I was greatly surprised to receive a most painful prick the first time I handled one. On examination I found that it had greatly enlarged tibial barbs, which no doubt discourage insectivores such as monkeys.

Probably the insect with the largest repertoire of defensive mechanisms is the Sulphorid bug *Laternaria phosphorea* (figure 18). It is cryptic when at rest but has a chitinous extension to its head. This can only be considered a 'horror mask' and is very like a diminutive alligator head, complete with dummy teeth and eye prominences. When seized, it exposes two large eye-marks on its hind-wings. Lastly, its abdomen is covered with a mould-like wax which probably makes it distasteful. We can assume that each of these defensive mechanisms has been developed during different periods in its past history when new predators demanded new defences. It is, in fact, unlikely that any species can build up more than one specialization at the same time [14]. Though so extreme in having so many lines of defence, it is probable that *Laternaria* has survived because of the absence of gross environmental changes which frequently must eliminate too highly adapted individuals, as happened to the Mastodon.

The classification we have adhered to up to now has the advantage of permitting us to envisage clear-cut reactions that are brought into play in a particular sequence. There remain, however, a miscellaneous series of highly specialized adaptations, some of which are alone sufficient to give protection: others take their place as only part of a behaviour complex.

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OTHER SPECIALIZATIONS

Great heat under a vertical sun produces its own complications. If one releases small Geometrid moths in the middle of the day over a bare and rocky area devoid of shade, but having trees at fifty yards distance, many collapse and fall dead to the ground: they are probably dehydrated in flight. It is not surprising that methods to avoid this danger have arisen. Many species at rest orientate themselves to the sun in such a way that they present their minimum surface area towards it, and hence their wings are always in the shade. For this reason it was most difficult to photograph *Tanusia brullaei* Blanchard, the Green Leaf Insect (figure 19), without the aid of a mirror, because it always kept its long axis vertical to the sun. Several *Thyrididae* and *Draconiae* species of moth use the same mechanism and pass the day standing 'on tiptoe' thereby throwing the minimum shadow and absorbing the least heat. Another mechanism, not previously described, is probably connected with deflection of heat or sunlight. Many insects that have to pass the day in direct sunlight have a blue or violet colouration: this is seen in the highest form in the Morpho butterflies. It is common, however, to a lesser extent in many moths that fly by day or are exposed at rest to sunlight. An interesting point is that the blue colouring, if limited in extent, is always present proximally over the vital areas and not over the distal portion. The blue-violet colour probably deflects certain rays of the sun and hence protects the insect [15].

Many Lepidoptera, such as *Perola brumalis* Schaus, make use of a greatly enlarged first pair of legs and spend the day with them sticking out conspicuously in front, giving a most unmothlike appearance (figure 20). Normally these legs are either entirely hidden beneath the insect or blend with the background on which it is sitting. Others, in widely differing genera, throw the abdomen over their head, and in this position they pass the day. In the majority of *Heterocera* (Moths) the abdomen lies concealed beneath the wings, with the ventral surface held tight against the resting surface. Examples of the former are found in the species *Megastes grandalis* Guen. [15] and *Casandria erratica* D. Jones (figure 13). In this last species it is of the greatest interest to note that, contrary to all other Lepidoptera known to me, it has a highly developed cryptic pattern on its ventral surface, which is exposed. This must have been built up by natural selection in association with the extraordinary position of abdominal dorsiflection in which it rests. In some species this strange position probably serves to keep the head and thorax in the shade of the abdomen (*Cicinnus* species). In others (*erratica*) it may be that if pecked by a bird, the body, not being found in the usual position beneath the wings, escapes injury.

Hairs and bristles are made use of throughout the Brazilian Insecta. Many lepidopterous larvae are covered with barbs or hairs of great length, as in the *Megalopygidae* (figure 22), and in many species these are highly poisonous. The moth *Dirphia hortensis* when attacked feigns dead and exposes its red and loosely haired abdomen. In the same way, the wax covering of certain specialized Hemiptera has been greatly accentuated, and this undoubtedly acts as a deterrent to predators. In the cryptic Cicada *Phoenix varigata* waxy strands cover the abdomen. Strangely, this wax is itself the food of a micro-lepidopteron, whose larvae feed on it. In other species (figure 23) hair bristles are developed around the periphery and these probably keep off the ants which swarm everywhere in Brazilian forests. In some instances, hair may serve to merge an outline into its background.

Transparent wings are made use of defensively in many ways. In the depth of the forest many species of butterfly of widely different genera show convergence of pattern, having transparent wings with black markings. They are all most difficult to follow in flight in the deep shade. Examples of this are *Zeonia licursis* Fab., and *Ithomia dryma* Hbn. *Syssphinx basirei* Schaus (figure 24) has transparent windows in the wings, which when at rest give a disruptive pattern when viewed from beneath.

Another special modification is the use of 'tails.' *Copiopteryx sonthannaxi* André [15], of which I found only one specimen, has two tails of great length, terminating in small light-coloured pennants, which in flight appeared to make a rustling noise. It is active at dawn and the tails are probably of service in deflecting attacks by bats, which are extremely numerous at that time.

So-called phosphorescence is frequently found in the Coleoptera: 'fire-flies' abound in all the forests. A *Pyrophorus* species which was noted by Darwin [1] is worth special mention. This Click-beetle has two luminous spots that can be seen at night at a distance of several yards. Its two 'head-lamps' possibly serve as a threat, or alternatively are bright enough to act as a visual aid in darkness. They are unlikely to be a sex attractant, as in some other beetles.

Brazil can probably boast some of the largest

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Lepidoptera and heaviest Coleoptera in the world. The noctuid moth *Thysania Agrippina*, has a wing span of just under 27 cm. Great size must confer advantages at times by shifting the species out of the range of certain predators.

I came across one other protective device not previously described among insects, but well-known in fish [16], namely the use of 'mirror reflection.' The pupa of *Mechanitis lysimnia* Fab. presents such highly mirrored surfaces that it reflects its surroundings wherever it pupates. By night it is easy to find with a torch because it appears as a bright spot of light.

CONCLUSIONS

I have given an interpretation of some of the more extreme defence mechanisms found in insects which I came across during seven weeks spent in Eastern Brazilian forests. During this period over 5000 selected specimens were caught and are now in the British Museum. I have suggested that extreme adaptive specialization may be commoner in South America than in the comparable African tropics. Furthermore, it is possible that there are more insect species in a given area of this region than elsewhere. Why could this be so in Brazil? Firstly, the most likely explanation is that the insects are based on a very large flora. There are four to five hundred tree species in eastern Brazil alone: each presents different buds, leaves, and trunks, and each offers a potential niche. The trunks alone can be white (as noted by Darwin [3]), red, or blue-green, according to the lichen species which cover them: each colour is exploited. Secondly, ruthless natural selection is ensured by a large number of insect eaters. There are three to four hundred species of birds in eastern Brazil alone, apart from lizards, frogs, monkeys, and other predators that rely on sight. Thirdly, the country has undergone no recent gross environmental changes such as glaciation: extreme adaptations have therefore not been eliminated. Finally, a variable countryside with suitable mountain ranges has been able to offer alternative accommodation during minor climatic changes.

Though equally complex and similar mechanisms undoubtedly exist in the African tropics and elsewhere, to me they appear not to occur so frequently. If this is so, an increased biological pressure occurring in a country offering an almost infinite number of biological niches may account for the quite incredible insect fauna of Brazil.

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REFERENCES

[1] DARWIN, C. 'Journal of Researches'. 1845.
[2] DARWIN, C. 'The Origin of Species'. (Sixth edition). 1859.
[3] DARWIN, C. 'The Beagle Diary'. 1839.
[4] WALLACE, A. R. 'Contributions to the Theory of Natural Selection'. London. 1870.
[5] DARWIN, C. and WALLACE, A. R. *Proc. Linn. Soc., Lond.*, III, 1858.
[6] COTT, H. 'Adaptive Colouration in Animals'. 1940.
[7] BATES, H. W. *Trans. Linn. Soc., Lond. (Zool.)*, 23, 1862.
[8] BATES. H. W. 'Naturalist on the River Amazon'. 1892.
[9] MOSS, M. *Novit. zool.*, 27, 1920.
[10] COLLENETTE, C. L. *Proc. zool. Soc., Lond.*, 1935.
[11] BRISTOWE, W. S. *Trans. R. ent. Soc., Lond.*, 475, 1924.
[12] DE RUITER, L. *Behaviour*, 4, 3, 1952.
[13] BLEST, D. *Ibid.*, 11, 209, 1957.
[14] HALDANE, J. B. S. *J. Genet.*, 1958.
[15] KETTLEWELL, H. B. D. *Life Magazine*, November 1958.
[16] HARDY, A. C. 'The Open Sea', Part 1, p. 226. Collins, London. 1956.

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Science in Israel

The creation of the independent State of Israel in 1948 was the culmination of long years of effort by leading Zionists throughout the world. Their leader was Chaim Weizmann, a unique combination of statesman and scientist. To his skill and pertinacity in the first role Israel owes its existence; from his vision in the second stems a great deal of the country's remarkable practical achievement during the past ten years. In the main, the world's statesmen have shown reluctance to be persuaded that science and technology are not merely interesting and important but essential to modern civilization: Israel may count herself fortunate in that her first leader not only had no need to be persuaded to accept this fundamental truth but lost no opportunity of convincing others of it. It is particularly fitting, therefore, that his memorial should be a scientific institute, at Rehovoth, that has been described as one of the most effective research complexes in the world.

The Weizmann Institute in its present form dates from 1949: the funds for its creation were subscribed to mark Weizmann's 70th birthday in 1944. Rehovoth was already an established scientific centre, however, for in 1934 a chemical research laboratory, the Daniel Sieff Research Institute, had been built; in this Weizmann himself found relaxation in research in his later years. This venture was a great act of faith, for at that time the whole future of Palestine was uncertain. Nevertheless, Weizmann saw clearly that if the independent State of which he dreamed was to survive, the help of science and technology would be indispensable. Events have proved how right was his bold conception of establishing a centre, primarily for fundamental research, in what was then an inhospitable wilderness.

Today the Weizmann Institute, beautifully set among trees and gardens, has on its staff 180 scientists and nearly 400 assistants, the great majority of them born in Israel. Its nine departments, well housed and well equipped, cover such varied fields as applied mathematics, nuclear physics, electronics, X-ray crystallography, organic chemistry, experimental biology, and biophysics. Where so much is good it is difficult to select for special mention specific examples of work in hand, but certainly the cancer research, the production of heavy oxygen, the preparation of large-ring conjugated systems, the investigation of the nidation of ova, and the work on polymers are all excellent. The outlook at Rehovoth is international, and its senior scientists travel widely to visit centres of research abroad. Conversely, increasing numbers of scientists from abroad are visiting Rehovoth to learn at first hand about research in progress and, not infrequently, to take some part in it: for such visitors excellent facilities exist. The Institute is not a teaching establishment, but in 1958 a post-graduate school was opened.

Impressive though the achievements of the Weizmann Institute are, it represents only part of a determined national effort to promote science. There are two national institutes for higher education, the Hebrew University at Jerusalem and the Technion at Haifa. The first of these has a remarkable history. It was first established on Mount Scopus in 1925, the fulfilment of ideas that were first put forward as early as 1882. Since the War of Independence in 1948 Mount Scopus has been in Arab territory, and although a fortnightly convoy is allowed to go through to the university, no more than a caretaker staff can be maintained. After some difficult years of existence in buildings scattered about Jerusalem, it was decided to build a new university on Girath Ram, a hill on the west of the city. Here many fine new buildings have been erected during the last four years, and more are planned. Of the total of rather more than 4000 students, about 1750 are in the faculties of science, agriculture, or medicine. The building of this completely new university is a remarkable achievement.

The Technion at Haifa is beautifully situated on Mount Carmel, and is the oldest scientific institution in Israel. Begun in 1912 as an institute for applied science, it was not completed in its original form until 1923. Now it has 3000 students —studying for degrees in all the principal branches of engineering—and a dozen new buildings have been built in recent years. The Technion serves the dual purpose of supplying trained engineers for Israel's industry and of carrying out industrial research: in recent years part of the latter has been done under contract for other countries—another example of Israel's international outlook.

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The antibiotics in microbiology

E. P. ABRAHAM

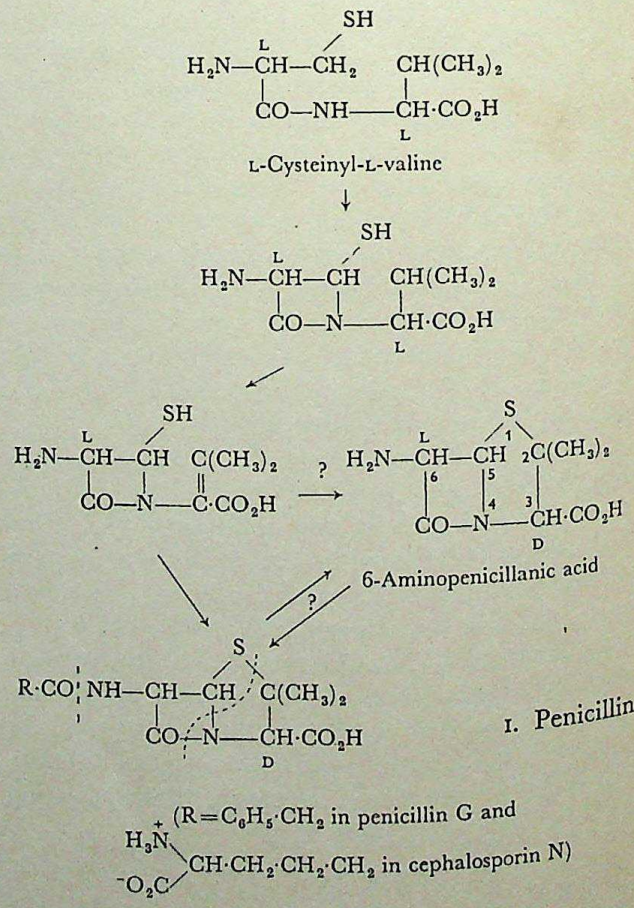
The spectacular therapeutic success of penicillin, and subsequently of other antibiotics, naturally led to the main concentration of effort in this field being directed towards practical application. Now, however, threads of continuity can be discerned where at first only a series of separate achievements was apparent, and results of fundamental microbiological interest have been achieved. The biosynthesis of antibiotics can be linked with that of other cellular constituents, and some light has been thrown on their mode of action.

Nearly twenty years have now passed since the discovery of the chemotherapeutic properties of penicillin by Florey, Chain, Heatley, and their colleagues and fifteen since the first publication on streptomycin by Schatz, Bugie, and Waksman. In that time we have passed from sporadic and accidental encounters with antibiosis by individual microbiologists to the systematic screening of many thousands of micro-organisms by the pharmaceutical industry, with the primary object of obtaining new drugs of clinical value. These expensive large-scale searches for therapeutically useful antibiotics have led to the discovery of chloramphenicol, the tetracyclines, erythromycin, and other substances that act as powerful antibacterial agents *in vivo*, and they have produced compounds of value against certain fungal infections. In some laboratories they are also aimed at the discovery of substances that will selectively inhibit the growth of tumour cells or viruses, though there is so far little evidence to indicate that they will have much success in this field.

The discovery of new antibiotics with useful chemotherapeutic properties has become a formidable task. In one survey of 10 000 actinomycetes from the soil some 2500 were found to produce antibiotics, but only ten of these substances were new and only one was clinically effective [1]. We are perhaps approaching a stage when the appearance of a new type of chemical structure in this field will be comparatively rare. It may thus be appropriate to consider the broad significance of the intensive work of the last two decades.

The striking achievements of the antibiotics in clinical medicine are common knowledge. Many bacterial infections that were once troublesome, dangerous, or even fatal can now be overcome. Were it not for evidence that the suppression of some types of infection facilitates the growth of others, and for the emergence among certain species of bacteria, in particular the staphylococci, of strains that are resistant to antibiotics, there would be good reason for satisfaction in this sphere of chemotherapy. However, the introduction of these particular substances into medicine involved no major additions to scientific theory. Once the fact that an antibiotic might show chemotherapeutic properties had been established, the field was exploited by skilled and systematic work of a largely empirical kind. Gratifying though the practical results have been, they yet seem intellectually unsatisfying.

Less pragmatic studies of the antibiotics are



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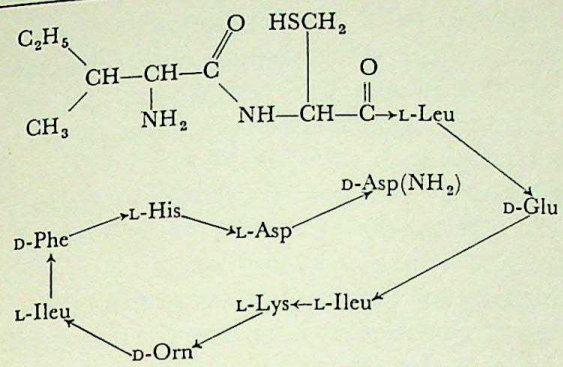
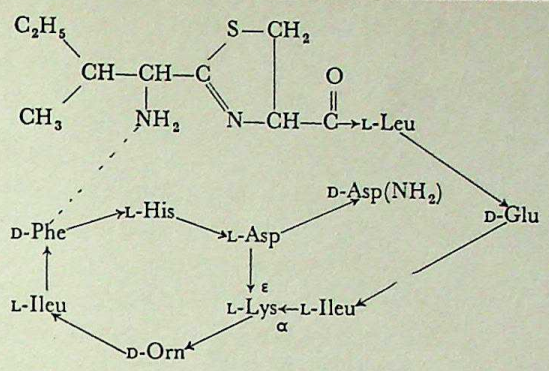


Hypothetical precursor of bacitracin A containing only α-peptide bonds



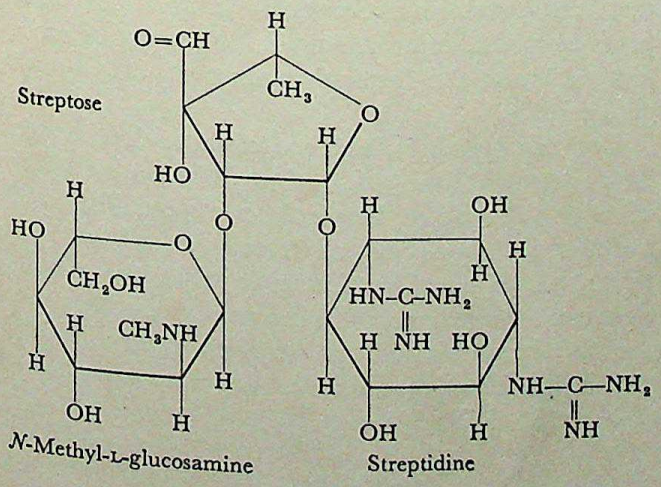
II. Bacitracin A

now beginning to produce results. A great number of microbial products have been revealed which would doubtless be still unknown had they not been labelled by their property of antimicrobial activity. The structures of many of these products have been determined, and a basis has thus been established for an attack on two problems that are of general interest to microbiology: how are these substances formed in the cell, and how do they exert their characteristic activity?

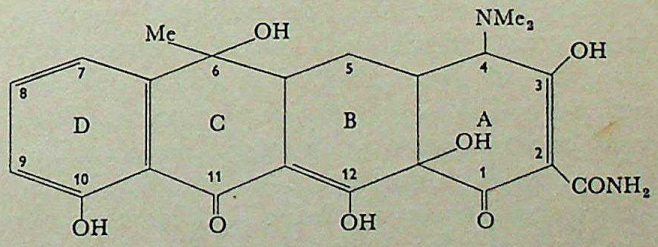
BIOSYNTHESIS OF ANTIBIOTICS

The antibiotics comprise a heterogeneous collection of compounds. A casual inspection, however, is sufficient to reveal that many of them can be grouped into families whose members are structurally related. *Penicillium chrysogenum* may synthesize a series of penicillins (I) which differ only in the side-chain (R), the main compound formed depending largely on the precursor of the side-chain that is added to the culture medium. *Bacillus licheniformis* forms bacitracin A (probably II) and a number of similar peptides in which valine is substituted for isoleucine. *Streptomyces griseus* produces not only streptomycin (III), but mannosidostreptomycin, in which a residue of mannose is linked to the L-glucosamine fragment of the molecule, and hydroxystreptomycin, in which the methyl group of the streptose fragment is replaced by a hydroxymethyl group. Other species of *Streptomyces* produce the various tetracyclines (IV); these include aureomycin and terramycin, which differ in their substituents at positions 5 and 7, and demethyltetracyclines, which have no methyl group at position 6. *Streptomyces* species also produce a group of antibiotics that are related chemically to erythromycin (V). These substances all contain large lactone rings, known as macrolides, attached to unfamiliar sugars or amino sugars (R_1 and R_2 in V).

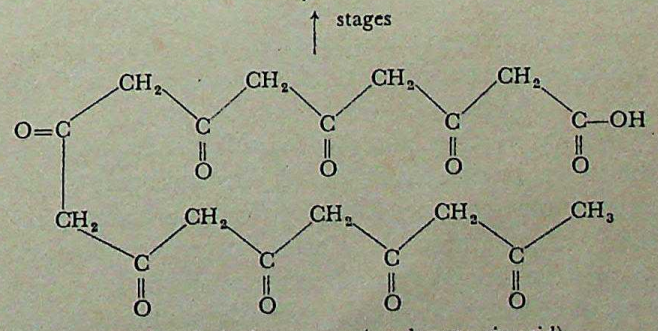
The different members of a single antibiotic family are often produced by the same species of organism, but this is not always so. A species of the genus *Cephalosporium* produces a hydrophilic



III. Streptomycin



IV. Tetracycline



Hypothetical precursor (octaketostearic acid)

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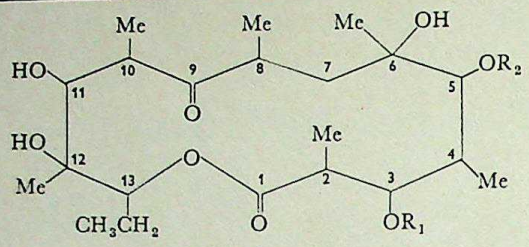


v. Erythromycin

penicillin, cephalosporin N, in which the side-chain is derived from D-α-aminoadipic acid, and a related substance, cephalosporin C, which does not contain a normal penicillin nucleus [2]. When we consider structural fragments of the antibiotics and not the complete molecules, relationships are more widespread. For example, the bacitracins contain a thiazoline ring which is structurally similar to thiazole rings in a very different antibiotic, micrococcin, obtained from a micrococcus and from *Bacillus pumilus* [3].

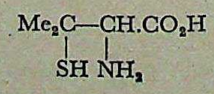
These examples illustrate the tendency for micro-organisms to produce numerous variations on certain structural patterns. It now appears that the patterns themselves, despite their striking differences, are commonly built from only a few types of structural unit: amino acids, acetate, and simple sugars. In this respect the biogenesis of antibiotics resembles that of a great number of other natural products.

Many antibiotics derived from bacteria and actinomycetes are polypeptides, and are thus clearly derived from amino acids, but the biosynthesis of these substances presents problems which have not arisen in connection with animal peptides and proteins. The antibiotics may contain amino acid residues which differ structurally from any of those present in proteins, and also residues which have the D-configuration. Their compositions may vary, in some cases, according to the amino acids present in the culture fluid, and their peptide chains are formed into large rings or are terminated by unusual groups. Free D-amino acids in micro-organisms appear to originate from enzyme-catalysed racemization, but it is uncertain whether these amino acids are incorporated as such into peptides.

An interesting member of this group of antibiotics is bacitracin A [2, 4]. Its molecule could arise from two types of cyclization in a dodecapeptide whose amino acids were joined by classical α-peptide bonds. Condensation of the carboxyl group of an aspartic acid with the ε-amino group of lysine would give the ring of six residues, while a condensation in an *N*-terminal isoleucylcysteine portion of the chain would give the thiazoline ring. But it is not clear whether the cells use specific mechanisms for making other members of the bacitracin family, or whether these peptides are formed because valine is imperfectly distinguished from the structurally similar isoleucine at a site where synthesis occurs. Our present knowledge of peptide hormones from the higher animals suggests that here genetic factors uniquely determine the structure of the molecule. For example, different insulins exist in which valine replaces isoleucine, but each appears to be synthesized only by a given species of animal.

With other antibiotics the possibility of dividing the structure into amino acid residues is less obvious but nevertheless clear. The dissection of penicillin into L-cysteine, D-valine, and an acid $R.CO_2H$, as shown in I, provides a well-known example. Studies by Arnstein and others have left no doubt that this dissection reveals the types of unit from which the antibiotic is formed in *P. chrysogenum* [5]. L-Cysteine labelled with ^{35}S, ^{15}N, and ^{14}C has been shown to be incorporated intact into the molecule. Identification of the origin of the D-valine residue has proved to be a more difficult problem, but it now seems likely that an early step in the synthesis is the formation of L-cysteinyl-L-valine: the latter, or an acyl derivative of it, is thought to condense to yield a β-lactam. Dehydration of the L-valine residue could then yield an intermediate from which the penicillin nucleus (6-aminopenicillanic acid) or a penicillin might be reached by addition of sulphur to the double bond, the configuration at the reformed centre of asymmetry (C_3) being dextro. 6-Aminopenicillanic acid has been obtained from the culture fluid of *P. chrysogenum*, but its isolation does not establish whether it is the immediate precursor of a complete penicillin structure or is formed from the latter by removal of an acyl group [6].

Enzymic systems which can effect such reactions have yet to be isolated, although an interchange of acyl side-chains between one penicillin and another has been demonstrated in cell-free extracts. It is notable, however, that the mould does not make a special amino acid, penicillamine, for the synthesis of this strange molecule but manipulates compounds that are normally available. D-Penicillamine



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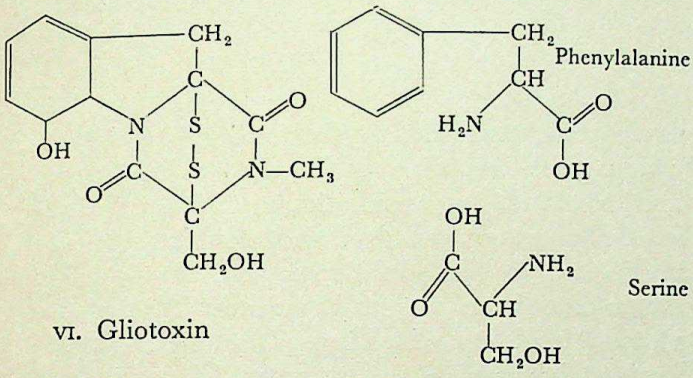
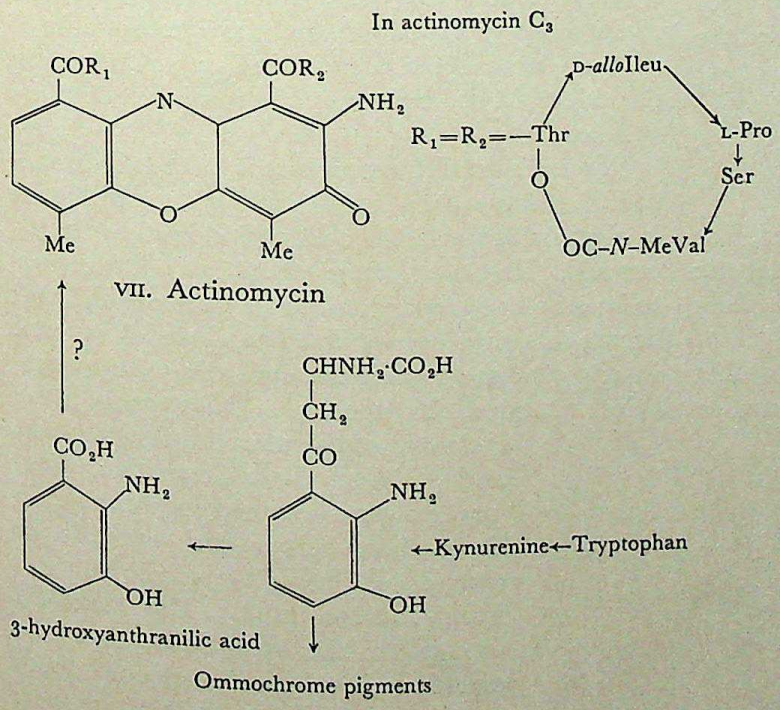
is a characteristic product of the chemical degradation of penicillin, and provides a starting point in a rational laboratory synthesis, but it does not appear to be formed in nature as an independent unit.

Further examples of antibiotics that arise from the condensation of amino acids are easily found. Gliotoxin, which was first isolated from a fungus more than twenty years ago, has recently been shown to have the structure VI [7]. In this we see



VI. Gliotoxin

the skeletons of phenylalanine and serine, to which two sulphur atoms have been attached in a unique manner. When added to the culture fluid, labelled phenylalanine is incorporated intact into the molecule [8]. The actinomycins (VII)—a family



of antibiotics with anti-tumour activity, produced by *Streptomyces antibioticus*—consist of a phenoxazone chromophore linked to two variable though related peptides (R_1, R_2) containing large lactone rings [9]. The phenoxazone can be dissected into two molecules of 3-hydroxy-4-methylanthranilic acid. Hydroxyanthranilic acid itself can be formed, by a series of enzyme-catalysed reactions, from the amino acid tryptophan. A derivative of hydroxyanthranilic acid is known to be the precursor of phenoxazone structures that are present in a group of pigments (the ommochromes) occurring in the eye of insects [10]. It is possible that a similar pathway, together with a process for the addition of a methyl group, leads from tryptophan to the actinomycin chromophore [9.]

Inspection of the structures of a variety of other antibiotics has led to the suggestion that they are derived from acetate. Several types of structural feature are indicative of this biogenetic origin. One is the distribution of oxygen or double bonds in such a way that the compound could be formed by acceptable modifications of poly-β-keto acid:

$$2x\mathrm{CH_3.CO_2H} \rightarrow x(\mathrm{—CH_2.CO.CH_2.CO—})$$

This type of process was suggested by Collie, as long ago as 1906, as being responsible for the formation of certain phenolic compounds. Collie's hypothesis was developed by Robinson and others [11], and in recent years its importance has been experimentally established by Birch in the case of phenolic plant products and mould metabolites [12]. A straightforward and elegant example of its application is provided by griseofulvin, an antibiotic obtained from several species of *Penicillium*, which has been used systemically for the treatment of fungal infections in man. When griseofulvin is produced in the presence of acetate whose carboxyl group is labelled by ^{14}C, the distribution of radioactive carbon in the molecule is precisely that required by the scheme shown (VIII) [11]. A more complicated example is provided [12] by the tetracyclines (IV). Here the experimental evidence is incomplete, but it supports the view that rings D and C, and part at least of ring B, are formed from acetate.

The skeleton provided by a poly-β-keto acid often requires the addition of extra groups or atoms, such as methyl or chlorine, before the final structure is reached. The frequent presence of extra methyl groups raises no obvious difficulty, for the *S*-methyl group of methionine is known to be transferable, in the presence of appropriate enzyme systems, to oxygen, nitrogen, or carbon in other compounds.

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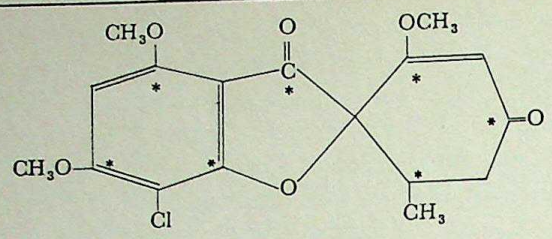
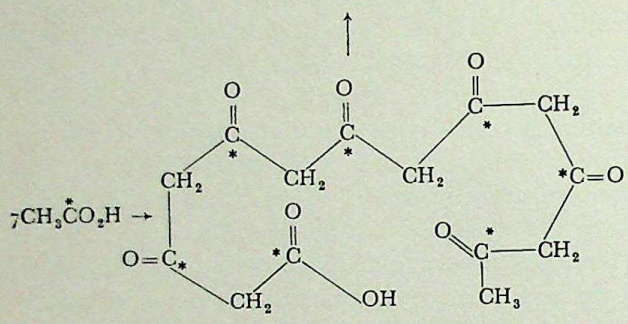
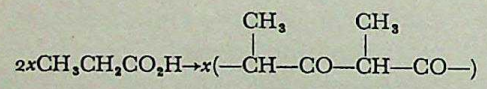


VIII. Griseofulvin



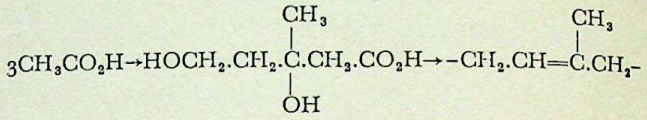
The methoxyl groups of griseofulvin, and probably also the methyl at C_6 of tetracycline, originate in this way.

The structures of the lactone rings of the erythromycin group of antibiotics are consistent with the assumption that they are formed from poly-β-keto acids. In erythromycin itself, however, methyl groups appear on the even-numbered carbon atoms of the ring with striking regularity (V). This has raised the question of whether the ring is made not from acetate but from propionate [13]:



The question has not been finally answered, but it may be that here, too, acetate is the biogenetic unit and that methyl groups are added separately to the skeleton that it forms.

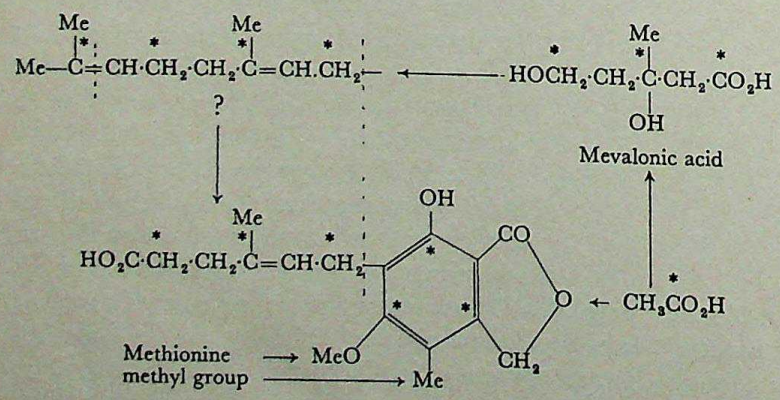
Work by Bu'Lock and Gregory suggests that modifications of β-keto acids formed from acetate may also lead to a family of antibiotics, produced by basidiomycetes, that contain acetylene links. It is evident, however, that the condensation of acetate in micro-organisms does not lead only to unbranched carbon chains. Three molecules of acetate can condense to yield mevalonic acid, a precursor of the isoprenoid units which make up the terpenoid groups of compounds:



Mevalonic acid

Among the terpenoid hydrocarbons is squalene, which gives rise, after cyclization, to triterpenes and sterols. A few antibiotics from fungi, including helvolic acid and cephalosporin P, appear to be related to the sterol-triterpene family [14]; others contain terpenoid fragments. Thus mycophenolic acid (IX), which is produced by *Penicillium brevicompactum* and was first isolated in crystalline form in 1896, contains a terpenoid side-chain linked to an aromatic nucleus. Work with isotopically labelled compounds has shown that both the side-chain and the nucleus are formed from acetate, but that only the side-chain is formed from mevalonic acid [15]. The integration of two main series of reactions and the introduction of methyl groups from methionine are necessary, as illustrated in IX, for the synthesis of the complete skeleton.

The variety of the structures derived from acetate that have been found among the antibiotics is already remarkable and will doubtless be increased. However, other structural units appear to be employed in the synthesis of some of the new sugars or amino sugars that have been discovered in many of the antibiotics, including the macrolides, produced by species of *Streptomyces*. The skeletons of the streptidine, streptose, and *N*-methyl-L-glucosamine fragments of streptomycin (III) all contain six carbon atoms and can all be synthesized from D-glucose but not from acetate [16]. The guanidyl groups of the streptidine may be transferred to the molecule from arginine. The way in which these novel transformations of D-glucose are brought about has still to be determined, but it is likely that some of the reactions involved are used for the synthesis of molecules other than



IX. Mycophenolic acid

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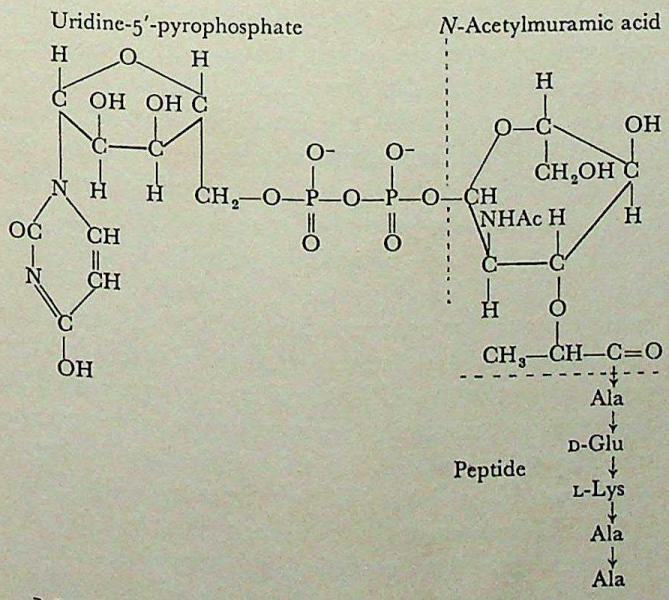
streptomycin. Two other antibiotics, neomycin and kanamycin, have now been shown to contain a fragment that is structurally related to streptidine.

MECHANISMS OF ANTIBIOTIC ACTION

The antibiotics show a range of activity against living cells that is as varied as their chemical nature, but those that are used systemically in medicine are all of necessity much more toxic to certain micro-organisms than to animal tissues. The mechanisms by which these chemotherapeutic agents exert their selective toxicity differ, at least in detail, from one substance to another, and each presents its own specific problems. Minor changes in certain parts of the molecule, and particularly changes in configuration at asymmetric centres, often result in a virtual loss of activity. Nevertheless, the types of cellular processes with which the substances interfere seem to fall into a limited number of categories, and we are beginning to discern what some of these are.

The study of changes in bacteria that are brought about by certain antibiotics is now contributing to our knowledge of the nature of the outer layers of bacterial cells. This work began in 1949, when Park and Johnson found that three uridine nucleotides accumulated in staphylococci that had been treated for a short time with penicillin. More recently the main nucleotide has been shown to consist of uridine pyrophosphate linked, through the *N*-acetyl derivative of a new amino sugar, to a peptide containing D- and L-alanine, L-lysine, and D-glutamic acid. Its structure may be represented thus:



Meanwhile evidence had accumulated that the cytoplasm of Gram-positive bacteria was surrounded by a fragile membrane able to withstand a high internal osmotic pressure because it was supported by a rigid cell wall. When certain organisms are treated with the enzyme lysozyme in a hypertonic solution of sucrose, their walls dissolve and they are converted to spherical bodies known as protoplasts. The latter are bounded only by a cytoplasmic membrane, and they burst when the external osmotic pressure is reduced by dilution of the medium with water. The rigid walls can be separated from other cellular material, however, by mechanical disintegration of the organisms followed by centrifugation. When viewed with the electron microscope they appear as skins that have collapsed, but the outline of the cells from which they come is still discernible.

Analysis of the cell walls of Gram-positive bacteria has shown that they contain only a relatively small number of different amino acids. They also contain the new amino sugar, named muramic acid, that was first found in the uridine nucleotides that accumulate in staphylococci treated with penicillin. The proportions in which muramic acid, alanine, lysine, and glutamic acid occur in the cell walls of *Staphylococcus aureus* appear to be the same as those in which they occur in the nucleotide, and the only additional amino acid in the cell walls is glycine.

The discovery of this relationship has led to the hypothesis that the uridine nucleotide is an intermediate through which the muramic acid-peptide must pass in forming new cell wall material, and that the nucleotide accumulates in the presence of penicillin because its use is prevented by the action of the drug [17]. Two different considerations give plausibility to this suggestion. Firstly, uridine nucleotides are known in other cases to mediate the linking of sugars and of amino sugars to form more complex compounds. Secondly, there is independent and convincing evidence that penicillin can interfere with the synthesis of bacterial cell walls. When certain bacteria are allowed to grow in a hypertonic medium containing penicillin they are converted to protoplast-like bodies which lyse when the medium is diluted with water [18]. When penicillin is added to staphylococci in a medium containing glucose, glycine, alanine, glutamic acid, and lysine labelled with ^{14}C, the incorporation of the lysine into the cell wall is greatly inhibited [19].

The picture which thus emerges of penicillin disorganizing specifically the growth of bacterial

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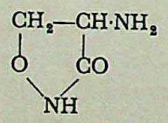
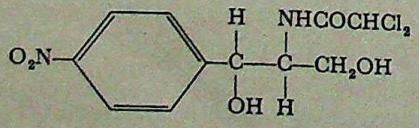
cell walls helps us to understand facts that were previously puzzling. The virtually complete lack of toxicity of penicillin to animal cells becomes understandable in principle, because these cells do not synthesize structures that are chemically similar to the walls of bacteria; both muramic acid and D-amino acids have so far been found only in micro-organisms. The fact that penicillin does not kill and lyse bacteria unless they are growing is explained if the formation of new cell wall is the only process affected, for it is not until the cell begins to grow that its existing wall becomes inadequate.

The synthesis of bacterial cell walls is evidently a complex process which could be inhibited selectively in more than one way. Several antibiotics have now been found to cause changes in staphylococci that resemble those produced by penicillin. Bacitracin brings about both a rapid accumulation of uridine nucleotides and the lysis of growing cells, and it inhibits the incorporation into the cell wall of amino acids labelled with ^{14}C [2, 19]. Similar, though less striking, changes are observed in the presence of D-cycloserine (x) [20]. Moreover, it is not only in bacteria that the cell walls may be a characteristic source of weakness. The chitinous walls of certain fungi appear to be damaged selectively by griseofulvin [21].



x. Cycloserine

Many antibiotics used in medicine exert no lytic action on sensitive bacteria, however, and the damage that they cause to the cells is quite different from that produced by penicillin or bacitracin. With a number of substances, including streptomycin, we are still uncertain about the type of cellular process that is primarily affected. But in the case of chloramphenicol and the tetracyclines much of interest has been learned [20]. These so-called 'broad spectrum' antibiotics all appear, despite the great difference in their chemical structures, to be inhibitors of the synthesis of bacterial protein. Chloramphenicol (the D-*threo* isomer of XI) is relatively specific in its



XI. Chloramphenicol

action. In antibacterial concentrations it immediately inhibits the synthesis of protein in *Staphylococcus aureus* and *Escherichia coli*, but it does not inhibit the incorporation of amino acids labelled with ^{14}C into the cell wall, nor does it prevent the synthesis of nucleic acid. With the tetracyclines the picture is similar, but less clear-cut, for in high concentrations these substances interfere with several cellular processes.

It seems that amino acids are first activated, for biosynthesis of protein, by the formation of mixed anhydrides with adenylic acid, and are then in turn transferred to at least two types of ribonucleic acid before the specific pattern of peptide bonds is established. Chloramphenicol and the tetracyclines may interfere at different points in this sequence of events in bacterial cells. The stereochemical situation is interesting. An L-isomer of chloramphenicol has little effect on the synthesis of protein (from L-amino acids) but strongly inhibits the synthesis of a D-glutamyl polypeptide [20].

The ability of bacteria to acquire resistance to antibiotics is one of many examples of the adaptability of micro-organisms, and its study impinges on basic problems of protein and nucleic acid synthesis. Two related questions may be asked about resistant strains. By what mechanism are they formed, and how do they differ from their sensitive parents? An elegant procedure invented by Lederberg, whereby samples of a mass of bacteria are first transferred from the surface of a nutrient agar plate to a velvet pad and are then printed on to other plates to give replicas of the first, has left little doubt that bacteria highly resistant to streptomycin can be formed without any contact with the drug [22]. When successive prints are made from a normal plate of *E. coli* to plates containing streptomycin, most of the organisms fail to multiply. A small number, however, grow into colonies of resistant cells and the latter appear at congruent sites on different plates. This is readily intelligible only if resistant cells, formed by rare mutations, already exist on the normal plate and are later selected in the presence of the drug. But it is by no means certain that random mutation represents the only mechanism by which resistance to antibiotics develops.

Remarkably little is yet known about the specific biochemical differences that must exist between resistant bacteria and sensitive ones of the same species; but in a special case, of medical importance, the immediate cause of resistance is clearly established. A number of bacteria can

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produce an enzyme, penicillinase, that brings about the rapid hydrolysis of penicillin. Among them are certain strains of staphylococci, and these strains may survive, while others are destroyed, during clinical use of the drug. The inherent ability to synthesize the enzyme appears to depend on a specific genetic character, but in some organisms the enzyme is normally present and in others its formation can be induced. In the latter, its rate of synthesis is greatly increased when penicillin is present in the medium. Penicillin is irreversibly bound by bacteria, probably near the cytoplasmic membrane, and the work of Pollock [23] has shown that with *B. cereus* only brief contact with the drug is required to establish a mechanism that will synthesize inducible penicillinase at a high and constant rate. The inducible enzyme appears to be identical with the constitutive enzyme formed by a mutant strain of the same organism. None of the available degradation products of penicillin show any power of induction. Nevertheless, the structural requirements of an inducer of the enzyme are not identical with those of a substrate of the enzyme. The penicillin-like antibiotic cephalosporin C is resistant to penicillinase, but induces its formation [24]. Although not a substrate, it combines with penicillinase and competitively inhibits the action of the enzyme on the true penicillins [25]. It remains to be seen whether a further member of the family can be found that has the specific action of a penicillin on cell-wall synthesis, but fails to activate the centre where penicillinase is formed, or that prevents the activation of this centre by penicillin while leaving cell-wall synthesis open to attack.

CONCLUSION

The main stream of biochemistry has been fed by studies on substances that are always found in living cells, such as carbohydrates, fats, proteins, and nucleic acids, and its progress has revealed that similar mechanisms are used in many different forms of life for the synthesis of essential structures and the provision of energy. The antibiotics appear at first sight to lie outside this widespread pattern. They are produced only by certain micro-organisms, and their antimicrobial activity is often highly selective. The biosynthesis and mode of action of these products might therefore be expected to illustrate the diversity rather than the unity of nature. In fact, this is only partly true.

What we now know, and can reasonably surmise, about the origin of the antibiotics points to the economy with which their novel and sometimes intricate structures are made. Amino acids and acetate, which feature as common structural units, have widespread functions in cellular metabolism. The condensation of acetate, as acetyl coenzyme A, to yield a β-keto acid, and of activated amino acids to form peptide chains, are familiar processes. So, too, is the transfer of a methyl group from *S*-adenosylmethionine to nitrogen, oxygen, or carbon in another molecule.

It may thus be only at certain stages in the synthesis of an antibiotic that enzymic mechanisms are involved that differ from the general patterns. Reactions in this category are responsible for the introduction of D-amino acids into peptide-like structures; for the intramolecular condensations that lead to penicillin, gliotoxin, and the tetracyclines; and for the building of conformations whose head-to-tail unions yield the large rings of the cyclopeptides and the macrolides. Some of them, however, can be regarded not as unique aberrations but as reflections of types of macromolecular organization that are shared by many species of micro-organism. D-Amino acids are commonly present in the cell walls of bacteria and actinomycetes, though they have not been detected in other forms of life. Large peptide and lactone rings, of a type previously unknown in natural products, have now been identified so often in the structures of antibiotics that their formation would seem to have a broad significance.

Our knowledge of the mode of action of the chemotherapeutic antibiotics parallels what we have learned about their biosynthesis. We can now define some of the main features of bacterial metabolism that are open to selective attack; one of these, the formation of cell walls, is a feature in which bacteria and actinomycetes differ from other kinds of cells. But the precise nature of the reactions that are inhibited has yet to be elucidated. So, too, have certain highly specific characteristics on which depend the degree of sensitivity to a given antibiotic. Why does the introduction of polar groups into the penicillin side-chain make the substance more active against some bacteria but much less active against others? Why does chloramphenicol inhibit protein synthesis more readily in bacteria than in animal cells? Factors, such as transport through cell membranes, which govern the accessibility of the drug to a sensitive structure may be concerned in some of these phenomena, but virtually nothing is yet known about them at the molecular level.

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REFERENCES

[1] WOODRUFF, H. B. and MCDANIEL, L. E. in 'The Strategy of Chemotherapy'. Cambridge University Press, London. 1958.

[2] ABRAHAM, E. P. and NEWTON, G. G. F. in 'Amino Acids and Peptides with Antimetabolic Activity'. J. and A. Churchill Ltd, London. 1958.

[3] BROOKES, P., FULLER, A. T., and WALKER, J. *J. chem. Soc.*, 689, 1957.

[4] CRAIG, L. C., KONIGSBERG, W, and HILL, R. J. in 'Amino Acids and Peptides with Antimetabolic Activity'. J. and A. Churchill Ltd, London. 1958.

[5] ARNSTEIN, H. R. V. *Ann. Rep. chem. Soc.*, **54**, 339, 1957.

[6] BATCHELOR, F. R., DOYLE, F. P., NAYLOR, J. H. C., and ROLINSON, G. N. *Nature, Lond.*, **183**, 257, 1959.

[7] BELL, M. R., JOHNSON, J. R., WILDI, B. S., and WOODWARD, R. B. *J. Amer. chem. Soc.*, **80**, 1001, 1958.

[8] SUHADOLNIK, R. J. and CHENOWETH, R. G. *Ibid.*, **80**, 4391, 1958.

[9] JOHNSON, A. W. *Chem. Soc. Special Publ.* No. 5, 1956; BROCKMANN, H., BOHNSACK, G., FRANCK, B., GRÖNE, H., MUXFELDT, H., and SÜLING, C. H. *Angew. Chem.*, **68**, 70, 1956; KATZ, E. and GOSS, W. A. *Nature, Lond.*, **182**, 1668, 1958.

[10] BUTENANDT, A. in 'Perspectives in Organic Chemistry'. Interscience Publishers Inc., New York. 1956.

[11] ROBINSON, R. 'The Structural Relations of Natural Products'. Oxford University Press, London. 1955.

[12] BIRCH, A. J. *Progr. Chem. org. nat. Prod.*, **14**, 186, 1957.

[13] WOODWARD, R. B. *Angew. Chem.*, **68**, 13, 1956.

[14] ABRAHAM, E. P. 'Biochemistry of some Peptide and Steroid Antibiotics'. John Wiley & Sons Inc., New York. 1957.

[15] BIRCH, A. J., ENGLISH, R. J., MASSY-WESTROPP, R. A., and SMITH, H. *J. chem. Soc.*, 369, 1958.

[16] HUNTER, G. D. *J. Microbiol.*, **2**, 312, 1956.

[17] PARK, J. T. and STROMINGER, J. L. *Science*, **125**, 99, 1957.

[18] LEDERBERG, J. *Proc. nat. Acad. Sci. Wash.*, **42**, 574, 1956.

[19] PARK, J. T. *Biochem. J.*, **70**, 2P, 1958.

[20] HAHN, F. E. *Symp. No.* 5, *4th Int. Congr. Biochem.*, 1958.

[21] BRIAN, P. W. *Ann. Bot. Lond.*, **13**, 59, 1949.

[22] LEDERBERG, J. and LEDERBERG, E. M. *J. Bact.*, **63**, 399, 1952.

[23] POLLOCK, M. R. *J. gen. Microbiol.*, **8**, 186, 1953.

[24] *Idem. Biochem. J.*, **66**, 419, 1957.

[25] ABRAHAM, E. P. and NEWTON, G. G. F. *Ibid.*, **63**, 629, 1956.

Book reviews

NUCLEAR SCIENCE

Annual Review of Nuclear Science, Vol. VIII, *edited by E. Segrè. Pp. vii+417. Annual Reviews Inc., Palo Alto, California.* 1958. $7.50.

This is in some way the mixture as before, but, even considering the high standard set by previous volumes, the ingredients this time are of quite unusual excellence. Those that were thrilled by Wick's recent review article on meson theory will not be disappointed with his 'Invariance Principles of Nuclear Physics'. It is a masterly account of what lies behind and beyond the great parity puzzle. Feshbach writes on the optical model and Segrè on antinucleons, each on the subject that is perhaps more than any other his own, and each does it very well. Of the other articles on physics, perhaps the most interesting is on hyperfragments, these strange nuclei in which one of the nucleons is replaced by a heavier baryon.

When the physicist turns to the other divisions he will find these of more interest to him than has been common in the past. The article on the control of radiation hazards in physics research is of great importance to him, and who could fail to find interest in 'Nuclear Astrophysics' or in 'Information Theory in Radiobiology', an attempt to account for the strange fact that radiation which does not affect more than one in 10^8 atoms in living tissue is enough to kill?

In this brief review it has been possible to refer to only seven of the thirteen articles that make up the volume, but the others are of equal variety and interest. L. R. B. ELTON

ORGANIC CHEMISTRY

A Text-book of Organic Chemistry, *by J. Read and F. D. Gunstone. Pp. xii+610. G. Bell & Sons Ltd, London.* 1958. 37*s.* 6*d. net.*

This work has been substantially rewritten, and, while the plan of the book remains essentially the same, the text has been thoroughly revised. The layout is now more attractive and readable.

The introductory historical survey tracing the rise of organic chemistry is brought up to date with a concise account of modern ideas of structure, including a short section on the orbital theory. The next section consists of an excellent account of methods of purification and analysis, and the use of micro-analysis is emphasized.

The major part of the work, dealing with the main classes of compound, is very well laid out; modern methods are given, and both formulae and reaction processes are attractively drawn. The authors have a happy knack of choosing good examples, and of giving interesting facts not usually available in a book of this size. The last few chapters deal neatly with more advanced topics, such as terpenes and alkaloids, in a manner which will encourage further reading. In addition there are sections on reaction mechanism and aromatic character which are brief, but excellent.

This book should be of particular value to senior boys in schools, as advanced topics are explained with a clarity and brevity suited to this level.

P. M. H. DAVIS

ORGANIC CHEMISTRY OF SULPHUR

Aspects of the Organic Chemistry of Sulphur, *by F. Challenger. Pp. vii+253. Academic Press Inc., New York; Butterworths Scientific Publications Ltd, London.* 1959. 40*s. net.*

Sulphur is the cinderella element of

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organic chemistry: it is exploited, neglected, and rather despised by the many who pay homage to oxygen, nitrogen, or halogen, in a hydrocarbon frame. The redress which Professor Challenger brings is not the result of wand-waving but of a lifetime's devoted study. The aspects treated in his book are linked to the theme of the widespread and multiform occurrence of sulphur compounds in nature. The theme is not exhausted, such familiar topics as vitamin B_1, biotin, and penicillin being omitted, but excellent chapters are provided on natural sulphonium compounds (sulphides, sulphido-acids and sulphoxides are included), on mustard oils, on sulphur compounds from mineral sources, on biological methylation, and on the chemistry of co-enzyme A. Throughout the book emphasis is laid on the practical approach, and the first chapter offers the inexpert reader an introduction to the fundamental chemistry involved. Appropriately too, for this is a fascinating aspect, there is frequent discussion of the biochemical significance of some of the compounds. References appended to chapters and an adequate index complete the volume.

This book fills a need. It will be welcomed generally and can be consulted, read, or re-read with pleasure and with profit. J. D. LOUDON

CRYSTAL GROWTH

Growth and Perfection of Crystals, *edited by R. H. Doremus, B. W. Roberts, and D. Turnbull. Pp. xviii+609. John Wiley & Sons Inc., New York; Chapman and Hall Ltd, London.* 1958. £5 *net.*

This volume gives the proceedings of an international conference at Cooperstown, New York, on 27th–29th August 1958, and the editors must be most warmly congratulated on its prompt publication.

Many of the papers are directed to the problem of the origin and control of line imperfections in crystal growth; several of these papers deal with crystal whiskers, and discuss their dislocation content. Other papers describe mechanisms by which dislocations may be introduced into crystals, and two papers describe methods for growing large dislocation-free crystals of silicon and of silver bromide. The problem of growth from the melt may have been more closely defined as a result of the conference, which has emphasized the need for a better understanding of the nature of the liquid-solid interface. Dendrite formation, impurity effects, and polymer crystallization are also discussed. There is comparatively little about growth techniques.

The volume is expensive and bulky, but the bulkiness is the price that has to be paid for speedy publication. The contributed papers contain many striking photographs that show the beauty of recent techniques for the observation of dislocations, and the volume represents an authoritative conspectus of present knowledge. It is invaluable to any laboratory interested in crystal growth. R. V. JONES

BIOSYNTHESIS

A Ciba Foundation Symposium on Biosynthesis of Terpenes and Sterols, *edited by G. E. W. Wolstenholme and M. O'Connor. Pp. xii+311. J. & A. Churchill Ltd, London.* 1959. 45*s. net.*

The great virtue of these symposia and colloquia organized by the Ciba Foundation lies in bringing the leaders in a field together, and, this having been accomplished, the small and specialized audience brings out the best from the participants. Carefully prepared for publication, the results are unique summaries of current work and hypotheses. Without symposia such as these any attempt to get at grips with the subject would entail a well-nigh impossible task of reading original publications. This collection of seventeen papers deals with one of the 'growing points' of biochemistry and, as might be expected, the recurrent theme is that of mevalonic acid, the discovery of which some three years ago solved one of the problems in the biogenesis of steroids and, in doing so, stimulated many new lines of research.

It is perhaps a disadvantage inherent in the circumstances of presentation that a book such as this is not easy reading for those not themselves specialists. Possibly something might be done editorially to provide a remedy, even by commissioning an introductory article which would put the contributions in perspective and fit them into a scheme. In other ways something could certainly be done. For instance, in this volume surely the paper by Folkers and his associates on the discovery and elucidation of mevalonic acid should come first and the terse and allusive paper by Bloch, important as it is, should appear in a place where it would be less likely to deter the as yet uninitiated reader. As for the rest, the range is surprisingly wide: the application of some of the work to modern interest in hypercholesterolaemia will be clear: there is some complex terpene chemistry, the biogenesis of bile acids and carotenoids is dealt with, and enzyme problems are discussed at length. One might, in this last connection, quote one of the organic chemists: '. . . we have no right to assume that nature is using the methods of which we personally would approve.'

R. K. CALLOW

ZOOLOGY

Traité de zoologie: anatomie, systématique, biologie, *edited by P.-P. Grassé. Vol. XIII,* Agnathes et poissons —anatomie, éthologie, systématique. *Part I, pp. viii+924; part II, pp. viii+925–1812; part III, pp. vii+1813–2758. Masson et Cie, Paris.* 1958. *Each part, paper covers, fcs.* 12 000; *bound, fcs.* 13 000.

With the appearance, first of the ostracoderms and then of the jawed fishes, the possibility was opened for successful vertebrate exploitation of aquatic habitats and for the later evolution of terrestrial groups. Both possibilities were fully realized, giving these animals unique importance both in the range and success of modern fishes and in the indispensable evidence provided by fossil and archaic groups—recently dramatically reinforced by discovery of the coelacanth—on the course of vertebrate evolution. It is therefore reasonable that Volume XIII of this great treatise, undoubtedly the most important general account of zoology now being produced, should run to three parts containing a total of 2758 pages.

Twenty-two authors have contributed, some of them, notably the late Léon Bertin, being responsible for many sections. All are French with the exception of E. Stensio of Stockholm, to whom recourse has very rightly been made for the long and authoritative account of the ostracoderms, which follows a somewhat shorter description of modern cyclostomes by M. Fontaine. This account of the *Agnatha* occupies half of the first book.

The remaining contents of this part, and all of part II, consist of sections covering the various organ systems in all fishes. Descriptions of structure are admirably illustrated, the greatest care having clearly been taken to maintain a consistently high standard in line figures, half-tone reproductions (where alone some slight criticism might be

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permitted), and occasional coloured plates. There is an accompanying account of function, either dealt with by the same author or separately. One is perhaps most impressed with the sections dealing with sense organs, electric organs (both structure and function), the endocrine system, and with reproduction in its many aspects. But throughout there is a wealth of well presented and illustrated information with only occasional gaps, such as lack of reference to the work of Gray and Harris on locomotion.

The last part deals initially with the living fish, first with growth, races, and migrations (these by L. Fage), and then with ecology and the broader aspects of geographical distribution. The long account of classification, dealing with both modern and fossil fishes, which occupies the greater part of this volume is preceded by an interesting account of the history of classification, illustrated with an X-ray photograph of mummified *Lates niloticus* and reproductions of the title pages of the Renaissance works of Belon and Rondelet. Finally comes a general description of the only living crossopterygian, *Latimeria*, by J. Millot and J. Anthony, illustrated with excellent photographs, including a coloured plate of one of the ten undamaged specimens obtained off Madagascar during three years of organized collecting. But despite its interest this is only one short section in a work of major importance unlikely to be approached in value, let alone superseded, for many years to come. C. M. YONGE

VERTEBRATE ANATOMY

Cours d'anatomie comparée des vertébrés, *by Jean G. Baer. Pp.* 206. *Masson et Cie., Paris*, 1958. *Fcs.* 5000.

As the preface of this book says, vertebrate comparative anatomy provides an author with a 'prodigious subject, too old ever to be out of date'. This, however, is no excuse for foisting upon readers a work consisting mostly of old knowledge, and that often capriciously selected and sometimes wrongly explained. There is a brief section on classification, followed by a concise treatment of each individual organ system as it appears in the different types of vertebrate. The treatment is, at best, sketchy, with many gaps. Colour change is stated to be only under hormonal control, with no mention of innervation of the chromatophores. More serious, there is almost no mention of muscles, though much about the skeleton. This is, of course, an old difficulty for vertebrate comparative anatomists, but something could have been said about recent developments in knowledge of mechanisms of movement, both in the water and by tetrapods. The entire central and peripheral nervous system is dealt with in nine pages, of which only three are devoted to the brain. On the other hand, there is an entire chapter of 19 pages for the sense organs, though in the course of this the author manages to describe the pineal organ of Agnatha as being 'without a structure comparable to a retina' and yet to give a picture so vague as to be compatible with this statement.

The figures are printed as a separate part of the book and are all based upon classical pictures from other books '*rehaussées par l'emploi de couleurs conventionelles, excitent le sens d'observation du lecteur*'. Unfortunately, in many of them there is little for him to observe, and labels have been mostly omitted so that he may concentrate on 'the idea or principle expressed and then turn for confirmation to the text'. But he must be cautious about what he finds there! J. Z. YOUNG

SPIDERS

The World of Spiders, *by W. S. Bristowe. Pp. xiii* + 304. *Collins Publishers, London.* 1958. 30*s. net.*

Many excellent volumes have appeared in the New Naturalist series, and 'The World of Spiders' must surely rank among the best of these. Dr Bristowe has written the first full and authoritative general account of British spiders, based upon more than thirty-six years of observing and collecting in many parts of the world.

With fluent enthusiasm he recounts the role of spiders in folklore and literature, the history of British araneology, and the basic features of spider structure and behaviour, all interspersed with delightful anecdotes. The biology of each family is described in turn, and sufficient morphological detail is included to enable all the major genera to be recognized. Of particular interest is the chapter on 'The Origin of Spiders', in which a diphyletic origin of terrestrial Arachnida is postulated.

It is perhaps unfair to point out mistakes, especially when there are so few, but there are some minor misprints, and the dorsal spines of *Dysdera crocata* are on the fourth femur, not on the first.

No account of this book would be complete without mention of Arthur Smith's superb illustrations, whose accuracy reflects many hours of careful observation. This admirable book, which should be on every naturalist's shelf, will undoubtedly stimulate great interest in the study of spiders.

JOHN A. L. COOKE

ROCKET PROPELLENTS

Solid Propellent and Exothermic Compositions, *by James Taylor. Pp. vii* + 153. *George Newnes Ltd, London.* 1959. 25*s. net.*

Dr Taylor has given a very readable account of the nature and uses of a wide variety of solid fuels: some liquid fuels are also discussed, although in less detail. A good deal of the work described was carried out by Dr Taylor and his colleagues in the Nobel Division laboratories of Imperial Chemical Industries. The titles of the chapters, which are reasonably self-contained and can be understood without detailed knowledge of the subjects considered, indicate the scope of the work. They are self-sustained exothermic chemical reactions; gunpowder and pyrotechnics; explosives; initiating explosives; propellents; low-temperature gas-producing reactions based on nitrites and the 'Hydrox' blasting device; ammonium nitrate, guanidine nitrate, and nitroguanidine compositions; rocket motors; solid charges for rockets and propulsion; power cartridges; and gasless reactions.

It is natural that a book of this kind should have a practical bias, but Dr Taylor has also stressed the need for fundamental work on solid state reactions. He has in fact indicated a number of problems which should be studied from this point of view.

This book contains information previously unpublished except as internal reports, and for this reason it will be of value to specialists in this field.

A. D. YOFFE

HISTORY OF CHEMISTRY

Robert Boyle and Seventeenth-century Chemistry, *by Marie Boas. Pp. viii* + 240. *Cambridge University Press, London.* 1958. 30*s. net.*

By her study of the works of Boyle and a wide range of other chemical authors of or near his century, Miss Boas has rediscovered for herself, and here elaborates, the chief results of his labours in theoretical and experimental chemistry. She is, of course, by no means the first in modern times to do this with essentially the same

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conclusions; but she insists sweepingly that all her precursors have seriously distorted the matter. Many of her *obiter dicta* outside chemistry itself are naive and superficial; and her cavalier dismissal of earlier authorities' assessments —for example, of 'The Sceptical Chymist'—are far too aggressively dogmatic. Such defects flaw the spirit in which any work of scholarship should be done. Boyle himself remarked: 'a man may be a champion for truth without being an enemy to civility.'

Her account of iatrochemistry is good; that of the doctrine of qualities less so; of Boyle's corpuscular ideas she rightly recognizes the deep importance. Her interpretation of his usages of the term 'element' differs from that of earlier exponents. Throughout the book the quotations from original sources are copious and aptly chosen. I. MASSON

HISTORY OF CYTOLOGY

A History of Cytology, *by Arthur Hughes. Pp. x+158. Abelard-Schuman Ltd, London.* 1959. 21*s. net.*

This useful book outlines the development of the major branches of cytology. The author necessarily relies heavily on the historical researches of others, especially in the large part of the work that is devoted to the cell theory, but he has made his own contribution as an historian, and he blends his findings with those of others in such a way that the story runs fluently. Interest is maintained throughout. The style is vigorous, clear, and free from pomposity. The book comes at an appropriate time, when many who know little of the background of the subject are turning to cytology as one invention after another provides new insight into the nature of the cell.

There are a few mistakes. The ten illustrations taken from Warneck show polar-body formation in *Limnaea* ('*Lymnaeus*'), not in *Limax*. Benda's iron-alizarin method does not involve the use of haematoxylin. Ergastoplasm was first named in a paper by M. and P. Bouin (not Garnier), and is now known not to be filamentous. The word chromatid is wrongly used. The distinguished zoologist G. C. Bourne is described as 'an Oxford botanist'. These, however, are minor blemishes in a book that deserves to be widely read by biologists. JOHN R. BAKER

HISTORY OF BOTANY

Species Plantarum, *by Carl Linnaeus.* A Facsimile. *Vol. I, pp. xiv+176+560. Vol. II, pp. xvi+640+148. The Ray Society, London. Vol. I,* 1957. 50*s. net. Vol. II,* 1959. 60*s. net.*

As a contribution to the quarter-millenary celebrations, in 1957, of Linnaeus's birth, the Ray Society undertook the publication of this facsimile of his most important work. A first volume which appeared in 1957 contained 560 of its 1200-odd pages, together with a 176-page introduction by W. T. Stearn. The introduction is designed to place the *Species Plantarum* in its full Linnean setting. This is well worth doing because the *Species Plantarum* is in fact closely integrated with Linnaeus's other work and is by no means the isolated opus it is sometimes taken to be. The project is now completed with a second volume containing the remainder of the facsimile itself, together with an appendix by W. T. Stearn and J. L. Heller clarifying Linnaeus's references to earlier authors.

The production of this facsimile is not merely an act of historical piety. The *Species Plantarum* is the internationally accepted starting point of modern botanical nomenclature, and as such is still a fundamental reference book. The original printing of 1753 was small, and surviving copies are collectors' pieces. Two previous facsimile printings in 1907 and 1934 have left the requirements of libraries and plant taxonomists still unsatisfied, and the present printing is designed first and foremost to fulfil a practical need. W. O. JAMES

HISTORY OF BRAIN STUDY

The History and Philosophy of Knowledge of the Brain and its Functions, *edited by F. N. L. Poynter. Pp. x+272. Blackwell Scientific Publications, Oxford.* 1958. 22*s.* 6*d. net.*

This volume includes almost all of the contributions to a three-day symposium held in London in the summer of 1957 under the auspices of the Wellcome Historical Medical Library. It could be maintained that the scope of the symposium was far too large, extending as it did from classical antiquity up to the present and ranging over a wide variety of cerebral and psychic functions. To the reviewer there is little of scientific interest in speculative attempts to describe the functioning of the brain when they are based upon the crude and often erroneous observations of past centuries. But, no doubt, the amazing compilation here presented should have a salutary influence in causing us to realize that even now our speculations on brain function are based upon very inadequate observations and may at some future time seem just as unwarranted as the speculations here assembled! Particularly valuable are the very erudite account of Descartes's ideas of brain function, and the several accounts by neurologists of ideas on brain function and consciousness with special reference to Hughlings Jackson. It is unfortunate that there is so little sign of integration, particularly as the subject is the brain, the integrator *par excellence.*

The book is very well produced, and there is a good index. J. C. ECCLES

HISTORY OF TECHNOLOGY

Man the Maker: A History of Technology and Engineering, *by R. J. Forbes. Pp. xv+365. Constable & Co. Ltd, London.* 1958. 30*s. net.*

The author, who is professor of the history of pure and applied sciences in antiquity at Amsterdam, first wrote this book for an American public in 1950. The new edition brings up to date the selective bibliography—which includes a handful of references to German and French sources—and has an extended epilogue on Technology and Progress. The development of 'man the maker' is traced from the time of the palaeolithic cave-dweller pondering the uses of fire to the United States citizen of our own generation, who supplements the physical strength of an easily wearied human frame from energy resources more than 2000 times as great *per caput* as were available in 1776.

It would be unreasonable to expect meticulous accuracy in a *tour de force* such as this not very long volume clearly represents. Instead, the reader will be grateful for an interesting and remarkably comprehensive narrative. The more discerning will also welcome the attempt, of which the technical expert commonly fights shy, to relate the record of invention and discovery which, since cities first rose on the banks of Euphrates and Nile, have so often changed tempo but never direction, to the far less certain chart of man's spiritual odyssey. Having shown how 'each new technique is born of the questions and needs of the times', Professor Forbes ends by asking: 'But were our questions, seen from the social angle, always the right ones?' The growth of technology has an often neglected bearing upon the problems of general history. T. K. DERRY

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Notes on contributors

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M.A., D.Phil.,

Was born in 1924 and was educated at Dulwich College, London, and Queen's College, University of Oxford, where he read chemistry. After a year's research at Reading University he read biochemistry at the University of Cambridge, and then spent three years in the Biochemistry Department, University of Chicago. In 1951 he returned to Oxford as lecturer in biochemistry in the Department of Agriculture, where he has remained, with the exception of a year's sabbatical leave at Johns Hopkins University. His research has been mainly on the biochemistry of the mammary gland.

A. S. LAUGHTON,
Ph.D., F.R.A.S., F.R.S.A.,

Was born in London in 1927 and was educated at Marlborough College and King's College, Cambridge. After three years' research at the Department of Geodesy and Geophysics, Cambridge, he received the John Murray studentship for Oceanography and studied for a year at Columbia University, New York. In 1955 he was appointed a Senior Scientific Officer at the National Institute of Oceanography, where he is now working on the exploration of the floor of the deep oceans.

A. RAISTRICK,
Ph.D., M.Sc.,

Was born in Yorkshire in 1896 and was educated at Bradford Grammar School and Leeds University, where he graduated in civil engineering and gained a Ph.D. in geology. He was Lecturer and Reader in Applied Geology, Kings College, Durham University, until his retirement in 1956. His researches have been into the nature and constitution of coal and in mining and engineering technological history.

H. LUNDEGÅRDH,
Ph.D.,

Was born in Stockholm in 1888. He studied at the University of Stockholm (Ph.D. 1912) and subsequently with Pfeffer in Leipzig and Klebs in Heidelberg. From 1916 to 1926 he was an assistant professor at the University of Lund. He was appointed professor of plant physiology and anatomy at the Agricultural Research Institute in *Experimentalfältet* (Stockholm) in 1926, and was head of the Institute of Plant Physiology at Ultuna-Upsala from 1937 to 1955. He established the Ecological Station at Hallands Väderö in 1917 and a laboratory for spectrophotometry at Penningby, Sweden, in 1947. His main research interest in the period 1928–40 was the development of spectrometric methods for studies in biochemistry and geochemistry.

H. B. D. KETTLEWELL,
M.A. (Oxon and Cantab), M.B., B.Chir., M.R.C.S., L.R.C.P.,

Was born in 1907 and educated at Charterhouse and at Caius College, Cambridge. He qualified in medicine at St Bartholomew's Hospital, London, and subsequently held a number of hospital posts. In 1949 he became a Nuffield Fellow in Genetical Research at Oxford University. He has conducted various expeditions in Africa and has also undertaken research in Brazil, Canada, and elsewhere. He is the author of numerous papers which deal with field ecology, in particular, with the rapid evolution of the black forms of certain species of moths, the phenomenon referred to as industrial melanism. He has also produced two scientific films demonstrating slow and rapid evolution in insects, his most recent one being 'Darwin and the Insect Adaptations of Brazil', which he made for the Darwin Centenary last year.

E. P. ABRAHAM,
M.A., D.Phil., F.R.S.,

Was born in 1913 and was educated at Queen's College, Oxford. He is a Fellow of Lincoln College, Oxford, and a Senior Research Officer at the Sir William Dunn School of Pathology. He was a Rockefeller Foundation Travelling Fellow at the University of Stockholm in 1939 and the University of California in 1948. During the war he was associated with Sir Howard Florey, Professor E. B. Chain, and Sir Robert Robinson in the work carried out on penicillin at Oxford. Since 1949 he has studied the chemistry and biochemistry of a number of peptide antibiotics and other natural products with biological activity. In 1957 he gave the Ciba Lecture in Microbial Biochemistry at Rutgers University, New Jersey.

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